IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:	Confirmation No.: 6024
BONEAU, Michael D.	Art Unit: 3738
Appl. No.: 09/287,216	Examiner: Jackson, S.
Filed: April 5, 1999	Atty Docket: P106 DIV 3C (1737.2120007/DKSC)
For: **Endovascular Support Device and Method**	

Reply Under 37 C.F.R. § 1.111

Assistant Commissioner for Patents
Washington, DC 20231

Sir:

On April 17, 2001, the Applicant filed a CPA to continue prosecution in the above-captioned patent application. Applicant requests reconsideration of each of the rejections made by the Examiner in an Office Action dated October 18, 2000.

It is not believed that extensions of time are required beyond those that may otherwise be provided for in documents accompanying this paper. However, if additional extensions of time are necessary to prevent abandonment of this application, then such extensions of time are hereby petitioned for under 37 C.F.R. § 1.136(a), and any fees required therefor are hereby authorized to be charged to our Deposit Account No. 19-0036.

Remarks

The Examiner has rejected Claims 4, 7-8, 10, 11, 14-19, 22, 23, 25-27, 29, 30, 32 and 33 under 35 U.S.C. 103(a) as being unpatentable over Gianturco 4,580,568 in view of Palmaz 4,739,762. In additional, the Examiner has rejected each of the pending claims (4-

33) under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claims 1-7 of U.S. Patent No. 5,292,331 and claims 1-8 of U.S. Patent No. 5,891,190. Finally, the Applicant wishes to thank the Examiner for indicating that claims 5, 6, 9, 12, 13, 20, 21, 24, 28 and 31 define patentable subject matter.

The rejections under 35 U.S.C. § 103(a) are respectfully traversed. The Office Action of October 18, 2000 contends that it would have been obvious "to take the multiple stents of Gianturco and deploy them using a balloon delivery catheter as taught by Palmaz." This is incorrect for a number of reasons as outlined in detail below. In addition, the obviousness-type double patenting rejection is improper for the reasons set forth below.

Summary of the Interview with Examiners Willse and Jackson

The Applicant wishes to thank Examiner Willse and Examiner Jackson for the courtesies extended during the interview of Thursday April 26, 2001. At the interview, Applicant's representative explained that one of the primary purposes of the interview was to make certain that the scope of the claims were fully understood by the Office and that there were no misunderstandings regarding their scope. Specifically, the Applicant showed the Examiners an actual Medtronic AVE GFX 12 mm stent (expanded) and an actual Medtronic AVE Micro Stent® II 15 mm stent (as packaged). In addition, the Applicant showed the Examiners enlarged copies of photographs of these same stents as well as a photographic depiction of a GFX stent from the *Handbook of Coronary Stents*, 2d ed.(1998). These stents are made by the Assignee of the present patent application. During the interview the Examiners agreed that the claims as currently drafted covered these stents.

Applicant's representative also showed the Examiners examples of products that were sold by competitors of the Assignee of the present patent application. It was explained to the Examiners that the pending claims were specifically drafted to distinguish the prior art ***and*** to cover the competitor products. The Examiners acknowledged that the scope of the claims as drafted were sufficiently broad to cover these products. Specifically, Applicant showed the Examiner depictions of the following products: the Multilink Coronary Stent made by Advanced Cardiovascular Systems (ACS), the NIR stent (made by Boston Scientific), the JOSTENT Coronary stent made by Jomed, and the DivYsio stent made by Biocompatibles, Ltd. Each of these stent structures were shown to the Examiners by reference to the *Handbook of Coronary Stents*, 2d ed. (1998). Applicant's representative also explained that the term "sinusoidal" or "sinusoidally-shaped" was not intended to limit the shape to a mathematical sine wave. Examiner Willse correctly pointed out that he considered this language to mean that there was a generally zig-zag configuration and that the Office would interpret the language broadly as Applicant intended.

To remind the Examiners of the structure of these competitor devices and the structure of the Assignee's product, the Applicant has attached as **Exhibit A** Chapters 5 (the Assignee's stent), 6 (the ACS Multilink stent), 14 (the NIR stent), 19 (the Jomed JOSTENT®) and 20 (the Biocompatibles DivYsio stent) from the above-referenced *Handbook of Coronary Stents*. In addition, the Applicant showed the Examiners a depiction of a Cordis BX Velocity stent. This stent is interesting because it is marketed by Cordis, the assignee of U.S. Patent No. 4,739,762 to Palmaz. It was explained to the Examiners how the BX Velocity stent uses the sinusoidal ring technology claimed by the Applicant. The depiction of the BX Velocity stent was in the form of a copy of a photograph. A copy as

shown to the Examiner is attached as **Exhibit B**. The Examiners indicated that they understood that the claims as drafted covered the BX Velocity stent.

In the interview, the Applicant's representative also explained to the Examiner the reasons for patentability of the claimed invention. These arguments are discussed in detail below.

In the interview, the Applicant's representative explained to the Examiners that there were various litigations involving patents in the same chain as the present patent application. In conformance with 37 C.F.R. § 1.56 and MPEP § 2001.06(c) submitted along with this Response is a document entitled "Information From Related Litigation" for consideration by the Examiner.

The Double Patenting Rejection is Improper

The Examiner has rejected claims 4-33 under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claims 1-7 of U.S. Patent No. 5,292,331 and claims 1-8 of U.S. Patent No. 5,891,190. In the prosecution history of the parent of the '190 patent, Serial No. 08/172,420 (now abandoned), Examiner Brittingham made a restriction requirement between claims drawn to an endovascular support device, to a method of treating narrowing of vessels and to a method of manufacturing an endovascular support device. Hence, an obviousness type double patenting rejection of the present claims is improper as between the device currently claimed and the method claims of the '190 patent because of the restriction requirement made upstream of the current application. As for the double-patenting rejection based on the claims of the '331 patent, claims 4-26 and 30-

33 each call for either a plurality of "rings" (claims 4-10); a plurality of "circular members" (claims 11-26); or a plurality of "support members" (claims 30-33). A plurality of such rings or members would not have been obvious in view of the stent of claims 1-7 of the '331 patent because, while the '331 claims are broad enough to cover a stent having more than one ring, no such "plurality" is claimed in claims 1-7. Applicant requests that the Examiner withdraw the obviousness-type double patenting rejection of each of the claims with respect to the '190 patent and of claims 4-26 and 30-33 with respect to the '331 patent.

Claims 27-29 do not require a plurality of stent ring components. In order to expedite issuance of the present application, Applicant will file a terminal disclaimer upon indication that each of the claims are patentable.

Gianturco Teaches Away From The Proposed Combination

The proposed modification of Gianturco is contrary to the fundamental teaching and operation of Gianturco. Gianturco teaches a ***self-expanding*** stent. The ***self-expanding*** stent of Gianturco is first compressed and inserted into a sheath, which maintains the stent in the compressed diameter. Gianturco, col. 3, lines 5-11. It is delivered in a compressed state by advancing it through the vessel inside the sheath. *Id.* at 9-11. When it reaches the desired location within the vessel, a flat-ended pusher is used to hold the stent in place while the sheath is retracted, which in turn allows the Gianturco stent to expand. *Id.* at 14-21. The Gianturco stent operates as an expandable stent by relying on the elastic energy stored in the compressed stent structure prior to delivery to the treatment site. This is the fundamental and distinctive principle of operation of the Gianturco invention – a stent that uses elastic

energy or stress stored in the relatively sharp bends of its structure in order to be deployed at the treatment site. Such stents are well known in the stent art as either Gianturco stents, z-stents or, when connected in series, as connected z-stents. A sample of a Gianturco-type stent was shown to the Examiners in the interview of April 26, 2001. Attached hereto as **Exhibit C** is a copy of a photograph of the sample shown to the Examiners.

The Combination As Proposed By The Office Action Is Unworkable

The combination proposed in the Office Action – deploying a spring-type self-expanding stent on a balloon delivery catheter – would be completely contrary to the basic operating principle of Gianturco, and would be unworkable in practice. A Gianturco stent cannot simply be mounted on a balloon, since it would tend to elastically spring back to its full pre-compression diameter. The claim language in the present application, specifically recites "plastically deformable rings capable of retaining a compressed configuration when mounted onto a balloon catheter" (*e.g.*, claim 4). This language precludes the claim language from reading on the teaching of Gianturco. Accordingly, such a stent would not stay mounted on a balloon as the Examiner proposes unless it is constrained by a sheath. However, if the stent is a zig-zag spring constrained by a sheath, then a balloon would be unnecessary and would have no function, since the Gianturco stent is, by definition, self-expanding. Thus, what the Office Action proposes is impossible without defeating the fundamental principle on which Gianturco operates—a stent that operates within the elastic range of the metal from which it is made so that it is self-expanding.

The Examiner's modification of Gianturco for use with a balloon catheter delivery amounts to an unworkable, unsatisfactory modification of the Gianturco stent since the proposed modification would effectively destroy the Gianturco stent's ability to operate as a self-expanding stent. Such a rejection under 35 U.S.C. § 103 is improper. *See* MPEP 2143.01 ("If the proposed modification or combination of the prior art would change the principle of operation of the prior art invention being modified, then the teachings of the references are not sufficient to render the claims *prima facie* obvious. *In re Ratti*, 270 F.2d 810, 123 USPQ 349 (CCPA 1959))."

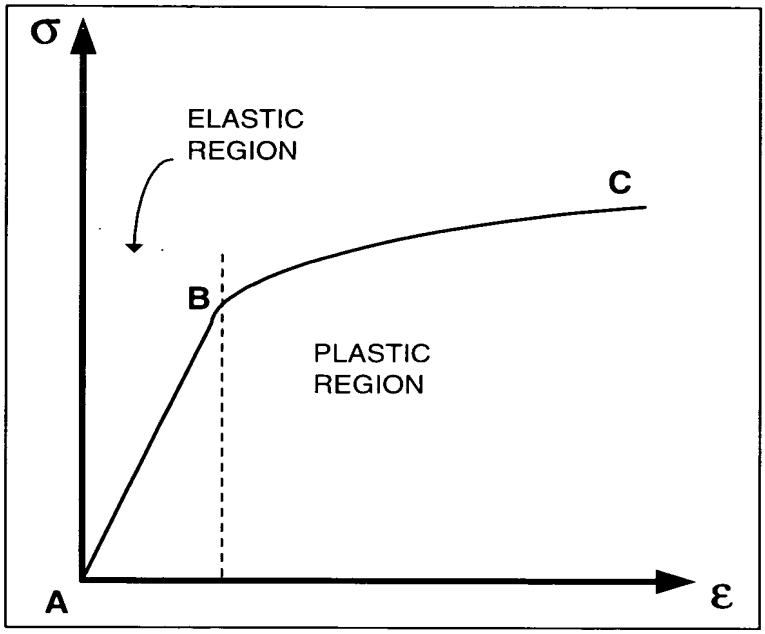
Making A Gianturco Stent Plastically Deformable Would Not Have Been Obvious

While not the basis of the Examiner's rejection, Applicant would like to address and preempt any contention that under U.S. law it would have been obvious at the time the invention was made to make a Gianturco self expanding stent design plastically deformable so that it *could have been* balloon expandable as taught by Palmaz.[1]

The Gianturco stent is made of stainless steel wire. Gianturco, col. 2, lines 48-52. Designing a stent to be either self-expanding, as taught by Gianturco, or balloon-expandable, as taught by Palmaz requires an understanding of the stress-strain relationship of steel, as well as knowing how to maximize the desirable characteristics of the stent under consideration. All materials deform or bend due to stress. First, steel undergoes elastic

[1] As noted in the German Nullity decision attached as an exhibit to the litigation statement filed herewith, such a contention was the basis relied upon by a German Court in a nullity action for revoking the German counterpart of the Boneau European patent that shares the same priority application as the present application. Such a decision applying foreign law is erroneous and is currently under appeal, but, of course, has no relevance to the present application which involves different claims and different law. *See, e.g., Medtronic, Inc. v. Daig Corp.*, 789 F.2d 903, 907-08 (Fed. Cir.), cert. denied, 479 U.S. 931 (1986).

deformation, and, once the stress becomes great enough, it undergoes plastic deformation. An illustration of this is shown below in a stress strain diagram. Please note that the diagram is for illustrative purposes only and is not intended to depict the characteristics of any specific material.[2]



Self-expanding stents are inherently designed to operate within the elastic region of the material (in the above diagram, the region AB). A self-expanding stent, like Gianturco, is compressed into a sheath, delivered inside a sheath, and is thereafter held by a pusher while the sheath is retracted, so that it springs or recoils back to its original shape due to the elastic behavior in the region AB. *See* Gianturco, col. 3, lines 5-21. Thus, self-expanding stents depend upon recoil in the elastic region to operate.

---

[2] To assist the Examiner in the event that additional background information is desired, attached hereto as **Exhibit D** is an excerpt from Marks' Standard Handbook for Mechanical Engineers (McGraw-Hill 1996) regarding the stress-strain relationship of materials.

Balloon expandable stents are fundamentally different: they operate in the region where stress in the material is beyond that in the elastic region, *i.e.*, in the plastic region (the region BC in the above diagram). *See, e.g.*, Palmaz '762, col. 4, lines 18-19; col. 7, line 65 - col. 8, line 1. In contrast to the Gianturco self-expanding stent, where substantial recoil is essential for operation, recoil must be minimized in a balloon expandable stent so that it may be expanded and fixed in the vessel without the need to substantially over-expand the vessel in order to accommodate recoil. Such over-expansion of the stent in turn may cause the *vessel* to be over-expanded, and could lead to vessel injury, which may be one of the causes of restenosis. In any event, balloon expandable stents by definition do not return to their original shape even after the external deforming load is removed.

A designer of a self-expanding stent seeks a stent configuration which will offer the ***maximum*** recoil. In contrast, a balloon expandable stent designer wants a stent configuration that ***minimizes*** recoil.

Dr. Gianturco describes the manner in which his zig-zag stent configuration is self-expanding. The Gianturco '568 patent provides a direct relationship between the construction of the stent and its behavior as a self-expanding stent by explaining that the bends store the elastic energy (referred to as "stress" in Gianturco), which in turn causes the stent to operate as a self-expanding stent:

> One embodiment of the method of the present invention might involve inserting a stent by compressing a stent including a wire formed in a closed zig–zag configuration into a first shape wherein the zig-zag configuration includes side-by-side closely adjacent straight sections joined by bends with a stress therein. The compressed wire stent is then moved into a sheath. The sheath is then located with the distal end thereof in a passageway with the compressed wire within the distal end of the sheath. The sheath is then removed from the passageway while holding the stent in

> place, whereby the stress in the stent causes it to expand in the passageway to hold the passageway open and enlarged.

Col. 1, line 64 - col. 2, line 8.

The Gianturco '568 patent also teaches that

> The straight sections 12 of the stent are joined by *bends 13 which are relatively sharp*. Thus, in one specific embodiment of the invention, the bends 13 are at a radius of no more than 0.2 cm. This specific embodiment of the invention includes wire 10 which is stainless steel of 0.018 inch O.D. The stent is resiliently expandable from the compressed first shape of FIG. 4 into a second shape illustrated in FIGS. 1, 2 and 6, wherein the straight sections 12 press against the walls of passageway to maintain the passageway open.

Col. 2, line 59 *et seq.* (Emphasis added.)

The opening page of EP 0 177 330 B1 (the European counterpart of the Gianturco patent, copy attached as **Exhibit E**, which was relied upon in the aforementioned German nullity proceedings) contains the following statement:

> This invention provides a stent comprising a single length of wire formed into a closed zig-zag configuration consisting of an endless series of straight sections joined by a plurality of bends, wherein the stent is resiliently depressible into a small first shape in which all of the straight sections are arranged side-by-side and closely adjacent one another for insertion into a passageway *with the bends having a stress therein, and wherein the stent is resiliently expandable by release of said stress into a second shape* in which all of the straight sections define a generally circular or cylindrical configuration for pressing against the wall of the passageway to maintain it open.

Page 2, line 29-35. (Emphasis added.)

Thus, Gianturco teaches that one can create a self-expandable stent by forming a series of straight sections connected by sharp bends and that this zig-zag configuration is effective for exploiting the elastic energy stored in the compressed stent for stent expansion

and retention against the vessel wall, *i.e.*, "the bends having a stress therein, and wherein the stent is resiliently expandable by release of said stress . . . ." Id at lines 32-33. Accordingly, a stent designer would have concluded that a stent with straight sections connected by bends provides a design that is highly elastic. In other words, the stent designer would have concluded that Gianturco's device operates in much the same way as a spring. The named inventor of the '762 patent, Julio Palmaz, confirms the spring operation of the Gianturco in Chapter 30 of Peripheral Vascular Imaging and Intervention, pp. 507-508, Mosby Year Book 1992. This Chapter, entitled "Overview of Intravascular Stents" is attached hereto as **Exhibit F**. In direct contrast, a balloon expandable stent designer wants to minimize elastic behavior. Indeed, this is confirmed by the Palmaz '762 patent relied upon by the Examiner. At column 1, line 38 - column 2, line 8, Palmaz discusses the disadvantages of self-expanding stents including self-expanding zig-zag stainless steel wire stents.[3] At column 8, lines 7 *et seq.* Palmaz describes the inherent aversion of a balloon expandable stent to recoil, or "spring back":

> The force to be applied to expand the tubular member 71 [of Palmaz's balloon expandable stent] ... must thus be sufficient to not only expand tubular member 71, but also to deform elongate member 75 ... whereby the portions of the elongate members 75 which pivot about the ends of connecting members 77 do not 'spring back' and assume their configuration shown in FIG. 1A, but rather retain the configuration thereof in FIG. 1B.

Col. 8, lines 8-17. (Emphasis added.)

Palmaz continues by noting another fundamental difference between his balloon expandable stent 71 and self-expanding stents:

---

[3] Palmaz does not mention Gianturco by name but his description "expanding stainless steel stents formed of stainless steel wire in a zig-zag pattern" is descriptive of the Gianturco stent under discussion here. The Gianturco Patent No. 4,580,568 is listed as one of the References Cited in the Palmaz '762 patent.

> It should be noted that when tubular member 71 has the first diameter, d, shown in FIG. 1A, or after tubular member 71 has been expanded and deformed into the second, expanded diameter, d', of FIG. 1B, tubular member 71 does not exert any outward, radial force, in that tubular member 71 is not a "spring-like" or "self-expanding member", which would tend to exert an outwardly radial force.

Col. 8, lines 21-28.

These teachings are powerful evidence that the combination of Palmaz and Gianturco is not only unobvious, but is contrary to the teaching of the prior art; it would not have been obvious to make a Gianturco stent plastically deformable.

The Combination Suggested by the Examiner can only be Made Using Impermissible Hindsight

Consistent with his teaching of using "relatively sharp bends", Gianturco also states that "[i]ncreasing the number of wire folds" will increase the dilating force, Gianturco '568, col. 5, line 13-14. It is submitted that these passages would have discouraged a stent designer from using a zig-zag configuration for a balloon expandable stent that relies on plastic deformation. Indeed, directly contrary to this teaching of Gianturco, the Boneau specification states (page 7, lines 12-15):

> It will be appreciated that the strength of the stent - that is, its ability to prevent restenosis - is inversely proportional to the number of peaks or turns in the stent, so that stents having a greater number of turns will be formed of larger wire diameters.

It is submitted that this fact would also direct one skilled in the art away from even trying to design a balloon expandable stent using the configuration of Gianturco.

Any suggestion of the combination of Gianturco's self-expanding stent with Palmaz's balloon expandable stent is not only contrary to the teachings of both references, but is only the product of impermissible hindsight. The teachings of the Gianturco patent, which seeks to maximize recoil by operating only within the elastic limit in order to function, are contrary to and incompatible with the teaching of Palmaz that balloon expandable stents must be subjected to expanding forces greater than the elastic limit of the stent material (*See*, Palmaz, col. 4, lines 18-19; col. 7, line 65 - col. 8, line 1) to avoid "spring back" (recoil). Hence, it is clear that it is only through improper hindsight, illuminated by the very disclosure of the Boneau specification at issue here, that an obviousness rejection based on the combination of Gianturco and Palmaz could be made. If only the prior art Gianturco and Palmaz teachings are considered in the light of ordinary skill in the art, not only is there no suggestion that their teachings be somehow combined or modified, but the teachings of each of these references are directly to the contrary and suggest an inherent incompatibility between self-expanding stents and balloon expandable stents. *Panduit Corp. v. Dennison Mfg. Co.*, 810 F.2d 1561, 1568 (Fed. Cir.) cert. denied, 481 U.S. 1052 (1987) (in considering obviousness, elements of separate prior art references cannot be combined when there is no suggestion of combinations anywhere in those references). The only motivation for the combination is the Boneau invention itself, which of course is wholly improper. *See, e.g.*, MPEP §2141.01.

Thus, Applicant respectfully submits that making the Gianturco self-expanding stent balloon expandable and balloon deliverable is not only contrary to the express teaching of Gianturco, and the result of impermissible hindsight, but also is contrary to what one of ordinary skill in the art would have done in light of the express teaching of the art. Finally,

as noted earlier, the modification suggested in the rejection would effectively destroy the Gianturco stent. This is an improper rejection under § 103. *See* MPEP § 2143.01.

Real World Experience Confirms that the Gianturco Self-Expanding Z-Stents Do Not Render Obvious the Claimed Invention

Dr. Gianturco, the named inventor of the Gianturco patent, also recognized that long stents tend to be less flexible, and have limited uses in curved vessels. *See, e.g.*, Duprat, Gianturco, et al., *Flexible Balloon-Expanded Stent for Small Vessels*, Radiology 1987 (attached as **Exhibit G**). At page 277, the authors discuss the advantages of balloon expandable stents, and the disadvantages (lack of longitudinal flexibility) of the Gianturco stents. There are numerous articles which discuss Gianturco stents but none that are known to the Applicant suggested making a Gianturco stent balloon expandable. A review of the IDS submitted in this case confirms this.

The circumstances of this case permit a unique opportunity to observe as a matter of historical fact what a person of greater than ordinary skill in the art (Dr. Gianturco) actually did when he invented a balloon expandable stent. In a typical obviousness analysis, one must necessarily speculate as to what a hypothetical person of ordinary skill in the art would have done at some point in time in the past. Gianturco's rejection of his zig-zag configuration for a balloon expandable stent provides unquestionable evidence of non-obviousness.

Dr. Cesare Gianturco, the named inventor on the Gianturco patent, was a well-known figure in the stent art, with numerous stent- and catheter-related patents and articles to his name. Thus, he himself was not only one of ordinary skill in the art, but was, in fact, one

of *greater than ordinary* skill in the art. Dr. Gianturco was one of the pioneers in the history of stent development. Dr. Gianturco was well familiar with the self-expanding stent art, as well with the balloon expandable art. He was also well familiar with the use of catheters, including balloon catheters. This, therefore, provides a unique opportunity to actually observe not only what one of *ordinary* skill in the art, but also what one of *greater than ordinary* skill in the art, did when faced with a need to design a balloon expandable stent. When Dr. Gianturco himself was working on a balloon expandable stent, he emphatically did not take his own self-expanding stent design and modify it to make it balloon expandable. Dr. Gianturco is the named inventor on another stent patent, U.S. Patent No. 4,800,882. The '882 patent makes clear that, when Dr. Gianturco was developing a balloon-expandable stent, he went to a completely different "clamshell" structure, such as that illustrated in Fig. 1 of the '882 patent (see figure below):

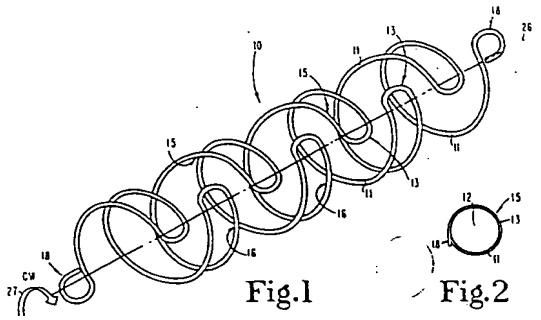


Fig.1 Fig.2

It is significant that in his '882 patent Dr. Gianturco specifically refers to his own self-expanding stent of U.S. Patent No. 4,580,568 (Col. 1, lines 21 et seq.) and rejects this and other stent configurations in favor of the "clamshell" structure for a balloon expandable design. Thus, Dr. Gianturco, an expert in the art, did not consider it obvious to simply take his own design (with which he was well familiar) and modify it to make it balloon expandable. Applicant also invites the Examiner's attention to another article of which Dr.

Gianturco is a coauthor, Charnsangavej *et al.*, *Stenosis of the Vena Cava: Preliminary Assessment of Treatment with Expandable Metallic Stents*, Radiology, 1986, pp. 295-298 (copy attached hereto as **Exhibit H**). At page 298, middle column, Dr. Gianturco and his co-authors state, when referring to the Gianturco self-expanding stent, that "[i]ts expansile mechanism is also simpler than that of the Palmaz graft, which uses an angioplasty balloon to expand the graft." This 1986 article demonstrates that Gianturco not only knew of the Palmaz balloon expandable stent prior to the 1987 filing of his application for his '882 patent, but also that experts in the field, including Dr. Gianturco himself, did not consider it obvious to deliver the Gianturco stent on a balloon catheter, but instead believed that the self-expanding principle of operation of Gianturco provides a better delivery mechanism compared to the Palmaz balloon expandable art. This evidence alone should compel the withdrawal of the rejection under § 103(a).

Dr. Gianturco was not the only individual of greater than ordinary skill in the art working with Gianturco type stents and balloons. Dr. Josef Rösch and Dr. Barry Uchida are also well-known figures in the stent industry. Applicant invites the Examiner's attention to a 1987 Radiology article by Rösch et al., entitled *Experimental Intrahepatic Portacaval Anastimosis: Use of Expandable Gianturco Stents* (hereafter, EIPCA) (copy attached as **Exhibit I**). At page 482 of the article, a number of Gianturco stent configurations are illustrated. These various self-expanding stent configurations were developed and manufactured by the Rösch team. Applicant invites the Examiner's attention to the passage on page 482 of the article, which states with reference to a previously deployed self-expanding Gianturco stent that "the stent was then distended with a 10 mm angioplasty balloon, establishing EIPCA." The Examiner is also directed to page 121 *et seq.* of The

Twelfth Annual Course on "Diagnostics Angiography and Interventional Radiology" (March 23-26, 1987). In this article, entitled *Gianturco Expandable Stents in Experimental and Clinical Use*, Rösch *et al.* state: "when the expanding force of the stent is not sufficient, a balloon catheter is used to expand the stent to a desirable lumen." Id at 121. This article is attached as **Exhibit J**. This technique was known in the art as "balloon distention," "balloon assist," or "Swiss kiss." Applicant disagrees with the characterization in this article to the extent it appears to suggest that the balloon expands the stent as distinguished from permitting the stent to expand elastically. There is no suggestion in either of the Rösch *et al.* articles that a balloon is used to plastically deform the stent. Applicant believes that the balloon assist distends the vessel in which the stent is deployed, permitting the stent's elastic resiliency to expand the stent outwardly and thereby hold the distended vessel open.

As the EIPCA article demonstrates, there is no question that balloons, catheters, self-expanding Gianturco stents, and the Palmaz art, were all available to Dr. Rösch and his team, and were used by them. Nevertheless, despite experimenting with numerous configurations of Gianturco stents, as discussed and illustrated in the EIPCA article, researchers of *greater than ordinary* skill in the art – i.e., Dr. Rösch and his team – did not consider it obvious to modify Gianturco stents in the manner proposed in the Office Action. They did not convert the Gianturco self-expanding stent into a balloon expandable stent for balloon catheter delivery. Instead, even though they had all the information and materials available to them, they clung to the idea of using the Gianturco stent according to its basic principle of operation—as a self-expanding device.

Dr. Rösch himself has published other articles on the subject of self-expanding stents. There are also numerous articles in the medical literature discussing the Palmaz

slotted tube stents in the 1985-1989 time period. Nonetheless, Applicant is unaware of any suggestion in any of Dr. Rösch' articles that the Gianturco self-expanding stent should be modified in the manner proposed in the Office Action.

In sum, the historical record from the late 1980's unambiguously demonstrates that even those of greater than ordinary skill in the art did not find it obvious to modify the Gianturco self-expanding stent to make it balloon expandable, as suggested by the Office Action. Accordingly, it defies common sense that what clearly was not obvious to a number of highly respected researchers of *greater than ordinary* skill in the art at the time of Boneau's invention would, in fact, have been obvious to one of *ordinary* skill in the art.

Conclusion

Contrary to the contention in the Office Action, a Gianturco stent cannot be simply mounted on a balloon. In order to be balloon expandable, the fundamental and essential operating principle of Gianturco—reliance on elastic recoil—must be abandoned and impermissibly destroyed. A balloon expandable stent must operate in a different region of the stress-strain curve than Gianturco. It must be designed to minimize recoil, rather than to maximize recoil. It must then be deployed in a manner wholly contrary to what Gianturco teaches. None of this is even remotely taught or suggested by Gianturco or Palmaz. Indeed, numerous passages in both Gianturco and Palmaz teach away from such a modification, and when a person of extraordinary skill, like Dr. Gianturco himself, was presented with this problem and sought to design a balloon expandable stent, he abandoned the zig-zag configuration of his z-stents in favor of a coil-type design. Similarly, Dr. Palmaz also at

least implicitly, if not explicitly rejected the zig-zag design for a balloon expandable stent. Palmaz expressly acknowledged self expanding stents in general, and zig-zag self expanding stents in particular, and noted their disadvantages which he sought to overcome with a balloon expandable stent. Palmaz, col. 1, lines 38-55; col. 1, line 61 - col. 2, line 8; col. 3, lines 6-29. Like Gianturco, Dr. Palmaz was an inventor in the field of stents and an author of numerous articles. Presumably, Dr. Palmaz is a person having *extraordinary* skill in the field of the present invention. Nevertheless, he never suggested in his patents, or in any of the publications known to the Applicant to make a plastically deformable stent in a zig-zag configuration. Instead, he pursued his plastically deformable slotted tube design. *See*, Palmaz, col. 7, line 61 - col. 8, line 29.

Thus, since the modification as proposed by the Examiner was, in fact, not obvious to experts in the art, it clearly would not have been obvious to a person of ordinary skill. Seldom do real world events exist as they do here, which can give the Examiner comfort that an invention was not, in fact, and would not have been obvious.

All of the stated grounds of objection and rejection have been properly traversed, accommodated, or rendered moot. Applicant therefore respectfully requests that the Examiner reconsider all currently outstanding objections and rejections and that they be withdrawn. Applicant believes that a full and complete reply has been made to the outstanding Office Action and, as such, the present application is in condition for allowance.

If the Examiner believes, for any reason, that personal communication will expedite prosecution of this application, the Examiner is invited to telephone the undersigned at the number provided.

Prompt and favorable consideration of this Reply is respectfully requested.

Respectfully submitted,

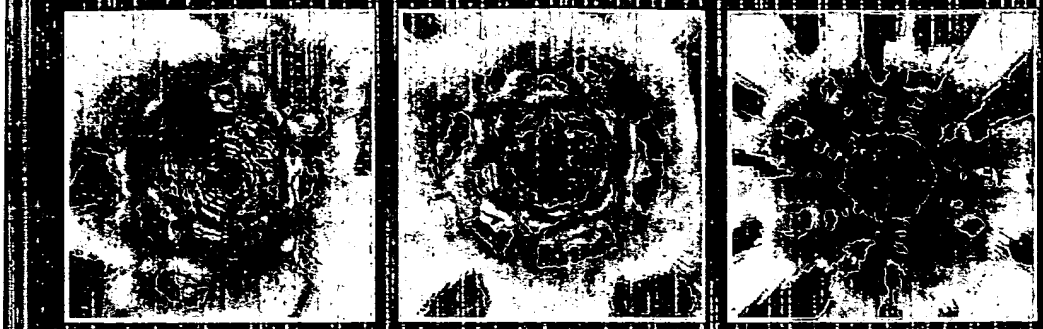
STERNE, KESSLER, GOLDSTEIN & FOX P.L.L.C.

David K.S. Cornwell
Attorney for Applicant
Registration No. 31,944

Date: June 11, 2001

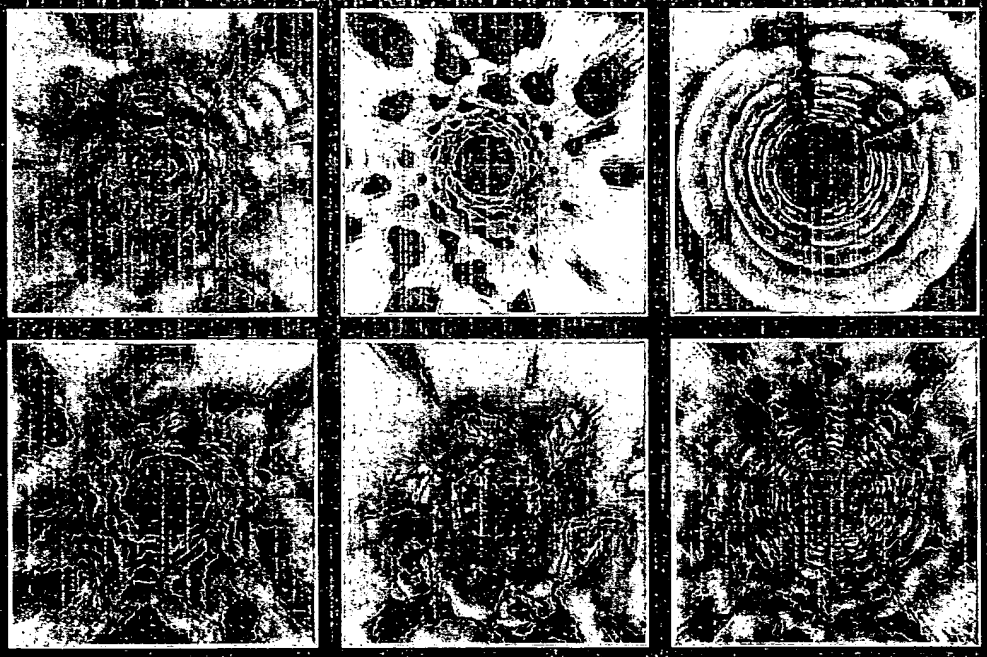
1100 New York Avenue, N.W.
Washington, D.C. 20005-3934
(202) 371-2600

P103-123.wpd



HANDBOOK OF CORONARY STENTS

SECOND EDITION



Rotterdam Thoraxcenter Interventional Cardiology Group

Patrick W Serruys • Michael JB Kutryk

HANDBOOK *of* CORONARY STENTS

Second Edition

Rotterdam Thoraxcenter Group

Edited by
Patrick W Serruys
Michael JB Kutryk

MARTIN DUNITZ

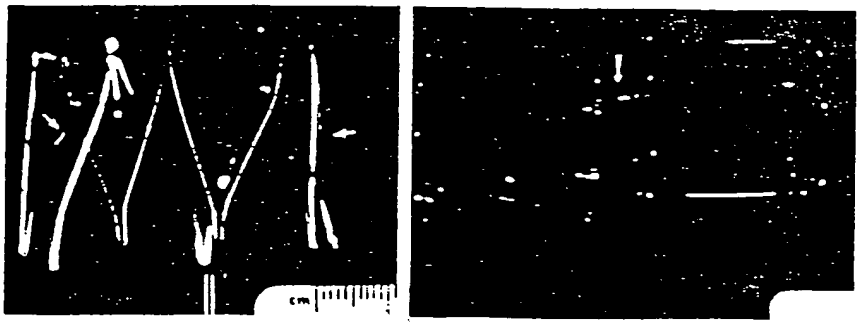
First published in the United Kingdom in 1997 by
Martin Dunitz Ltd
The Livery House
7–9 Pratt Street
London NW1 0AE

Second Edition 1998
Reprinted 1998

A CIP catalogue record for this book is available from the British Library .

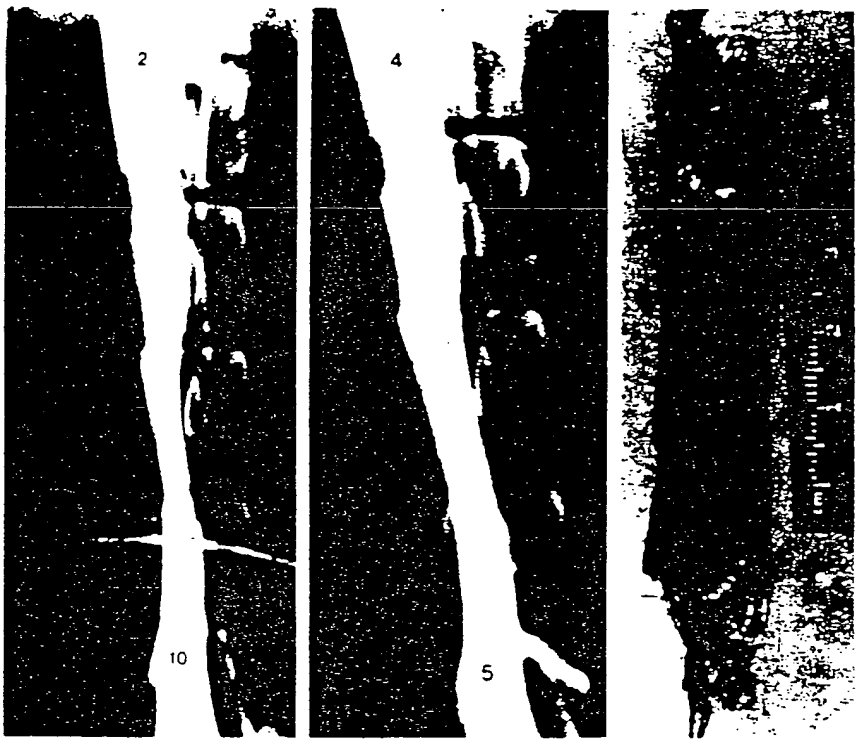
ISBN 1 85317 543 9

Composition by Scribe Design, Gillingham, Kent
Printed and bound in Spain by Grafos, S.A.



a. b.

Figure 1. (a) Gianturco stent with barbs (arrows). (b) Double stent. Two stents connected by a wire strut (arrow) allow a greater expansile force than a single long stent and provide better stabilization during release.



a. b. c.

Figure 2. Application of stents in experimentally induced caval stenosis in a dog. (Numbers in a and b represent pressure in centimeters of saline.) (a) Stenotic inferior vena cava after injection of absolute ethanol in the retroperitoneum. Pressure gradient across the stenosis was 8 cm of saline. (b) After placement of two single stents, pressure gradient was reduced to 1 cm of saline. (c) Pathologic specimen obtained 4 months after stent placement. The stents were covered by endothelium, incorporating them in the wall of the vessel.

Table 1
Effect of Stents on Inferior Vena Cava Diameter (mm)

Dog	Initial	Stenotic	After Stent Placement: Immediate	After Stent Placement: 4 Months Follow-up
1	15	5	7	9
		7	11	14
2	14	5	8	11
		9	14	14
3	14	5	9	12
4	16	4	7	9
		5	7	9

Note.—Caval diameters were measured at the different stenotic sites in dogs 1, 2, and 4.

a. b.

Figure 3. Failure of the stents. (a) Early migration resulted in a conical stent (arrows). (b) The closed end obstructed blood flow, and thrombosis developed.

abdomens were obtained at 1, 2, 7, and 14 days after stent placement. Inferior cavography and pressure measurements above and below the stenosis were performed at monthly intervals for 4 months. No anticoagulants or antiplatelet agents were given to the dogs during the follow-up period. The dogs were killed when the stents failed or 4 months after placement. Pathologic examination of the retroperitoneum and inferior vena cava was performed.

Results

The stents were successfully placed across the stenosis, and the patency of the experimentally induced stenotic inferior vena cava was maintained in four of the seven dogs. There was an immediate increase in the caval diameter, varying from 2 to 5 mm after stent placement (Table 1). Although the inferior vena cava did not expand to its original diameter or to that of a fully expanded stent, it did expand up to another 3 mm in diameter from the time of placement to the time of sacrifice (Fig. 2). None of the stents migrated.

There was resolution of the pressure gradients in three of the four dogs; one did not have a significant pressure gradient before stent placement. Normal pressure gradients were maintained throughout the 4-month follow-up in all four dogs (Table 2).

Pathologic examination of the inferior vena cava in these four dogs demonstrated the stents to be incorporated in the caval wall (Fig. 2). Endothelial proliferation completely covered the stents in all. There was no clot formation. The orifices

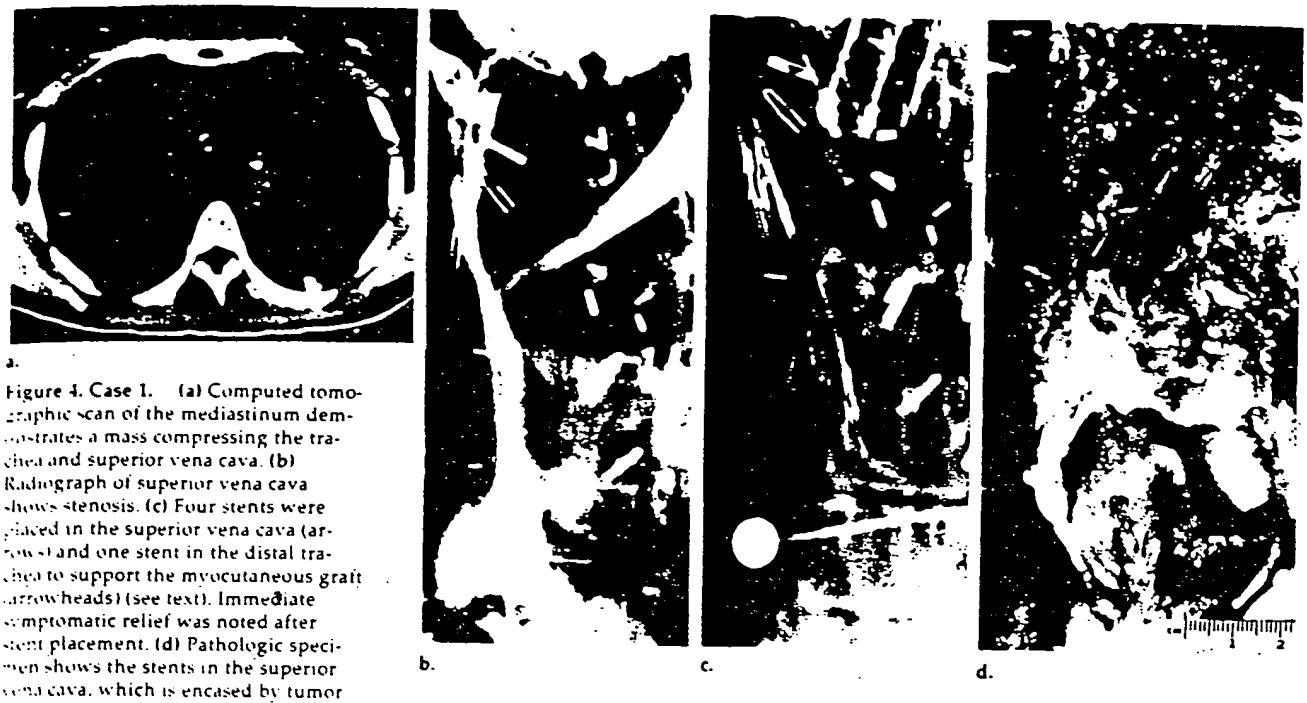


Figure 4. Case 1. (a) Computed tomographic scan of the mediastinum demonstrates a mass compressing the trachea and superior vena cava. (b) Radiograph of superior vena cava shows stenosis. (c) Four stents were placed in the superior vena cava (arrows) and one stent in the distal trachea to support the myocutaneous graft (arrowheads) (see text). Immediate symptomatic relief was noted after stent placement. (d) Pathologic specimen shows the stents in the superior vena cava, which is encased by tumor (arrow). Superior vena cava was patent with no clot formation.

of the veins that were bridged by the stent remained patent.

In the other three dogs, the stents failed to dilate the stenotic vena cava and resulted in occlusion. In the first of these three dogs, an attempt was made to place the stent across an occluded inferior vena cava. The stent could not reestablish the lumen but perforated the inferior vena cava, which resulted in retroperitoneal abscess. In the remaining two, attempts to place the barbless stents across the tight stenosis were complicated by migration as the stents were released from the catheter. The stents formed a cone, with the distal end expanded in the normal inferior vena cava and the proximal end closed in the stenotic portion (Fig. 3). This closed, proximal end obstructed blood flow, resulting in thrombus formation.

CLINICAL APPLICATION

Case 1

Severe stridor and a superior vena cava syndrome developed in a 42-year-old woman secondary to a poorly differentiated carcinoma of the trachea involving the mediastinum that did not respond to radiation therapy. Surgical debulking was attempted to alleviate her symptoms. The distal trachea was partially resected and reconstructed with a myocutaneous graft. However, the myocutaneous graft collapsed with each inspiration, and the patient required the assistance of a positive pressure respirator to breathe. The superior vena cava syndrome persisted.

Superior cavography demonstrated stenosis of both innominate veins and the superior vena cava at their injunction. An attempt to dilate the stenosis with two angioplasty balloon (9-mm-diameter) catheters was not successful.

Four regular barbless stents, each 3 cm in diameter and 3-cm long, were placed in the right innominate vein and superior vena cava (Fig. 4). Another stent was placed into the distal trachea to prevent the collapse of the myocutaneous graft.

After stent placement, there was immediate relief of the superior vena cava syndrome, and the patient was able to breathe without assistance. Systemic chemotherapy was instituted but resulted in severe myelosuppression and sepsis. She died 3 weeks later. At autopsy, the superior vena cava was patent, and no clot formation was seen on the stents. The tracheal stent maintained the patency of the myocutaneous graft.

Case 2

An 82-year-old woman was admitted with edema of both legs and the lower abdomen. She had had a retroperitoneal leiomyosarcoma that had been treated with surgical resection and radiation therapy 8 years prior. She also had had chronic pancreatitis and retroperitoneal fibrosis that necessitated a choledochojejunostomy to relieve an obstructive jaundice 8 months before she was admitted with edema.

Inferior cavography demonstrated a marked stenosis of the vena cava at the level of L-4 with paravertebral collaterals. The pressure gradient across the stenosis was 20 cm of saline.

Table 2
Effect of Stents on Pressure Gradients (cm of saline)

Dog	Before Stent	After Stent	4 Months Later
1	NS	NS	...
2	5	2	2
3	8	1	1
4	6	3	2

Note.—NS = not significant.

Three barbless stents, each 2.5 cm in diameter and 3-cm long, were placed across the stenosis (Fig. 5). Immediately after stent placement, the pressure gradient was reduced to 10 cm of saline. However, one stent migrated and lodged in the hepatic segment of the inferior vena cava. On the next day, that stent migrated into the right ventricle, necessitating the placement of a bird's nest filter in the inferior vena cava to prevent migration of the other stents. Additional stents with a larger diameter (3 cm) were placed across the stenosis.

The edema of the legs disappeared and did not recur. The patient experienced no clinical problems related to the stent lodged in the ventricle. She died 5 months later with progressive disease in the retroperitoneum and abdomen. At autopsy, the inferior vena cava (encased by the recurrent tumor) was widely patent, maintained by the stents, and was free of clot formation. The stent in the right ventricle was covered by endocardium with no clot formation.

DISCUSSION

The results of this animal experiment and limited clinical experience should be interpreted with caution. It appeared that in both the women and the dogs the stents had not expanded to their fullest diameters or to the original diameters of the vena cavas. However, they had allowed enough blood flow through the stenoses to decrease the pressure gradients. In case 2, the expansile force of the stent not only immediately neutralized or relieved the extrinsic compression from fibrosis or tumor on the vessel wall but also prevented progression of the stenosis.

The stents failed when they were placed in a thrombotic or occluded vessel. The presence of blood clot or intraluminal tumors may limit the use of the Gianturco stent. An intraluminal tumor will probably grow around the wires of the stent. Lysis of the blood clot by thrombolytic agents could be helpful before stent placement. Placement of the stent into a tight stenotic lesion may not adequately expand the lumen to allow sufficient blood flow, which would result in thrombosis. In such instances, balloon dilatation before stent placement should be considered.

Early migration of the stents occurred in two dogs. When released from the catheters, the stents tended to spring into the nonstenotic portion of the vessel and formed a cone, the narrowed end of which obstructed blood flow and resulted in thrombosis. To avoid early migration, double stents and barbed stents were used. As the leading stent was released from the catheter, the other remained within it, which allowed slight manipulation or change in position and thus better stabilization.

The stent in case 2 most likely migrated because the size of the inferior vena cava was underestimated. As demonstrated on the radiograph of the inferior vena cava obtained before stent placement, the caval diameter above the stenosis was only 1.2 cm, compared with the diameter of 2.5 cm after placement of the stents. Thus, a 2.5-cm diameter stent was apparently too small. To prevent such migration, the selection of the proper stent diameter and use of a barbed stent are recommended for fixation of the stent to the caval wall.

The expansile force of the stent increases with an increase in the caliber of the wire, in stent diameter, and in the number and angle of wire bends. However, an increase in length will decrease the expansile force. The expansile mechanism and the introduction of the Gianturo stent are much simpler than those of grafts made of nitinol wire. It spontaneously returns to its original shape after release without the changes in temperatures required in use of nitinol wire. Its expansile mechanism is also simpler than that of the Palmaz graft, which uses an angioplasty balloon to expand the graft. The ability of the Gianturco stent to expand slowly over time may also offer an advantage over the other types of stents.

Figure 5. Case 2. (a) Radiograph of inferior vena cava demonstrates the stenotic site (arrow) with paravertebral collaterals. (b) After placement of the stents, the inferior vena cava expanded, and the collaterals disappeared. A stent migrated to the hepatic segment of the inferior vena cava (arrowheads). (c) One day later, the stent migrated farther and lodged in the right ventricle (arrows) without clinical consequences. (d) Pathologic specimen shows the stent in the right ventricle, covered by endocardium. There was no clot formation (arrows).

Conventional treatment for stenosis of the vena cava secondary to tumor encasement is radiation therapy or chemotherapy (5–8). Successful relief of superior vena cava syndrome has been reported in as high as 94% of patients. Resolution of the signs and symptoms may have a latent period up to 3 weeks (5). For stenosis from surgical or postradiation fibrosis, the treatment is more difficult. Bypass surgery or surgical correction is considered a major undertaking and may not be worth the effort, particularly in patients who still have residual or recurrent tumor (9).

Clinical application of the Gianturco stent seems appropriate for further investigation, particularly in patients with a vena cava that is stenotic because of encasement from a tumor that has not responded to radiation therapy or chemotherapy or because of postsurgical and radiation fibrosis. ■

References

1. Cragg AH, Lund G, Rysav JA, et al. Percutaneous arterial grafting. Radiology 1984; 150:45–49.
2. Dotter CT, Buschmann RW, McKinney MK, et al. Transluminal expandable nitinol coil stent grafting: preliminary report. Radiology 1983; 147:259–260.
3. Palmaz JC, Sibbitt RR, Reuter SR, et al. Expandable intraluminal graft: a preliminary study. Radiology 1985; 156:73–77.
4. Wright KC, Wallace S, Charnsangavej C, Carrasco CH, Gianturco C. Percutaneous endovascular stents: an experimental evaluation. Radiology 1985; 156:69–72.
5. Davenport D, Ferree C, Blake D, Rabin M. Radiation therapy in the treatment of superior vena caval obstruction. Cancer 1978; 42:2600–2603.
6. Levitt SH, Jones TK Jr, Kirkpatrick SI, Bagardus CR. Treatment of malignant superior vena caval obstruction: a randomized study. Cancer 1969; 24:447–452.
7. Scarantino C, Salazar OM, Rubin P, Wilson G, MacIntosh P. Optimum radiation schedule in treatment of superior vena caval obstruction. J Radiat Oncol Biol Phys 1979; 5:1978–1995.
8. Dombernowsky P, Hansen HH. Combination chemotherapy in the management of superior vena caval obstruction in small cell anaplastic carcinoma of the lung. Acta Med Scand 1978; 204:513–516.
9. Doty DB. Bypass of superior vena cava: six years' experience with spiral vein graft for obstruction of superior vena cava due to benign and malignant disease. J Thorac Cardiovasc Surg 1982; 83:326–338.

5. AVE GFX STENT

Arterial Vascular Engineering, Inc., Santa Rosa CA, USA

Simon H Stertzer and Eugene V Pomerantsev

Description	Balloon expandable, sinusoidal-ring design with radio-opaque, 2 mm ellipto-rectangular elements. Sheathless and pre-mounted via proprictary methodology. Rapid exchange and over-the-wire delivery systems incorporating a moderately compliant PE material balloon. Available in lengths of 8, 12, 18, 24, 30 and 40 mm and diameters of 2.5–4.0 mm.

History	• October 1994 AVE began sales of its Micro Stent coronary stent line • December 1996 Release of GFX Coronary Stent line in 8,12,18 and 24 mm lengths (international markets only) • March 1997 CE Mark approval received for Micro Stent II

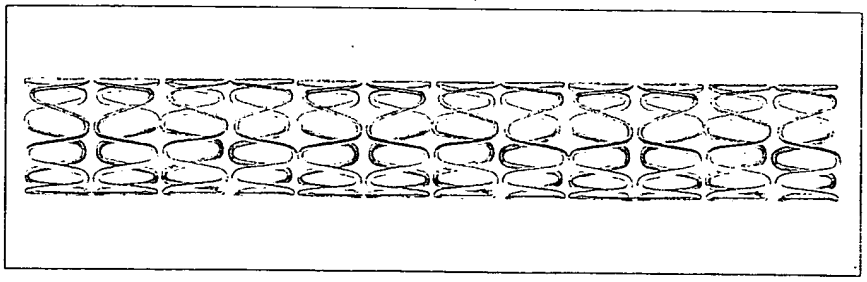


Figure 5.1: AVE GFX Stent.

Figure 5.2: AVE GFX stent on delivery system.

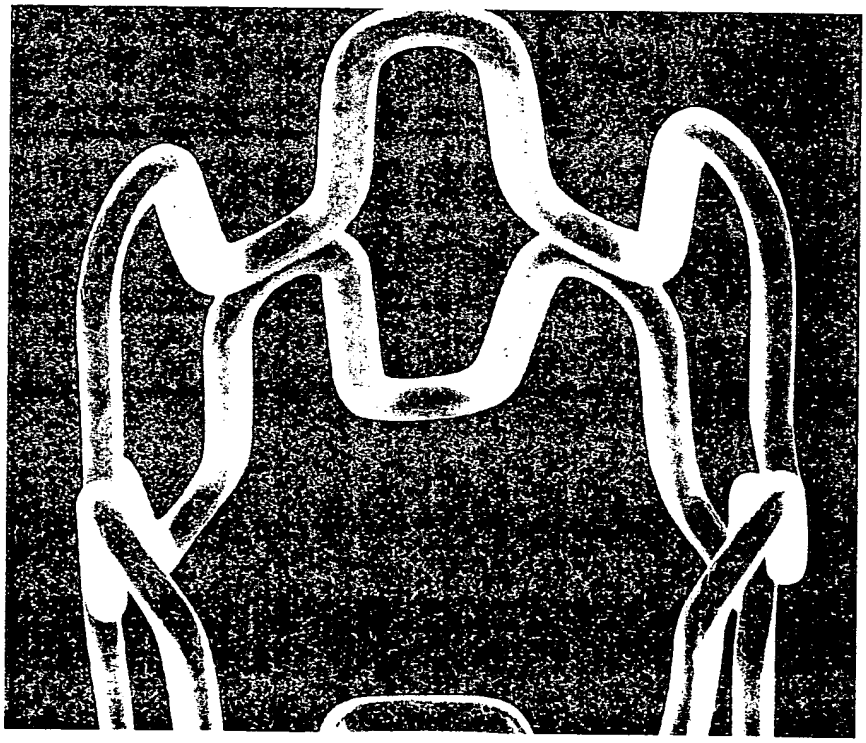


Figure 5.3: Electron micrograph of AVE stent.

AVE GFX technical specifications

Material composition:	316 L stainless steel
Degree of radio-opacity (grade):	Moderate
Ferromagnetism:	Non-ferromagnetic (MRI safe)
Metallic surface area (in expanded state):	~20% (3.5 mm diameter)
Stent design:	Proprietary, 2 mm segment, sinusoidal-ring, welded subunits
Strut design:	Ellipto-rectangular, electropolished
Strut dimensions:	2 mm long stent elements
Strut thickness:	0.005 inch (0.13 mm)
Profile(s):	
Non-expanded (uncrimped):	0.06–0.062 inch (1.5–1.6 mm)
Expanded:	
On the balloons:	0.060 inch (1.5 mm)
Longitudinal flexibility:	Excellent
Percentage shortening (on delivery):	None
Percentage shortening on expansion:	Negligible
Expansion range:	3.0–4.0 mm
Degree of recoil (shape memory):	<2%
Radial force:	High
Currently available diameters:	2.5, 3.0–4.0 mm
Recrossability of implanted stent:	Excellent
Other non-coronary types available:	Renal and iliac stent

AVE GFX stent delivery system

Mechanism of deployment:	Balloon expandable
Mechanism of expanding:	Balloon expandable
Minimal internal diameter of guiding catheter:	0.064 inch (1.6 mm)
Monorail system:	Yes
Balloon characteristics:	Semi-compliant
Balloon material:	PE
Guidewire lumen:	0.014 inch (0.36 mm)
Minimum recommended guide:	6 Fr
Premounted on delivery catheter:	Yes
Premounted on a high pressure balloon:	No
Protective sheath/cover:	No
Offered as a bare stent:	No
Position of radio-opaque markers:	Proximal and distal stent ends
Rated burst pressure of balloon:	10 atmospheres for 3.0–3.5 mm; 9 atmospheres for 4.0 mm
Delivery balloon compliance:	Moderately compliant
Delivery profile:	0.060–0.062 inch (1.5–1.6 mm)
Longitudinal flexibility:	Excellent
Recommended deployment pressure:	Nominal at 9 atmospheres
Further balloon expansion recommended:	Discretionary
Balloon dilatation and stent sizing:	Versatile, stent diameter entirely dependent upon delivery balloon diameter
Recrossability of implanted stent (Grade):	Excellent
Sizing diameter:	3.0–4.0 mm

Tips and tricks for delivery

The sheathless over-the-wire stent requires only 30 sec of negative balloon preparation and adequate lesion debulking or dilatation, similar to all stents. Bifurcation lesions may require placement of one stent in main lesion, dilatation through the stent crowns into a side branch and placement of the second stent through the first to complete the Y. The monorail system requires careful preloading before introduction into the body.

Indications for use

Bailout	High elastic recoil lesions
Ostial lesions	Total occlusions
Bifurcations	Restenosis
Tortuous vessels	Suboptimal PTCA
Long lesions	Suboptimal stenting
Small vessels	Adjunct to high-speed rotational atherectomy

Why I like my stent

- High flexibility
- Exceptional trackability
- Excellent conformability
- Moderate radio-opacity
- Optimal radial strength, minimal recoil
- Sheathless deployment system
- Low profile, pre-mounted delivery system
- Excellent vessel wall coverage
- Atraumatic, laminar stent design
- Suitable for wide range of applications
- Offered in broad range of sizes
- Rapid exchange and over-the-wire delivery systems

Case 1: Patient W., 49 yr. Stable angina, CCS Class III.

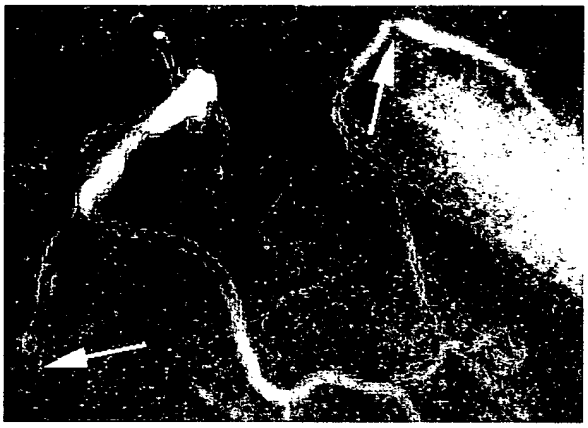


Figure 5.4: RAO 30°. LAD proximal occlusion (arrow), RCA distal occlusion (arrow).

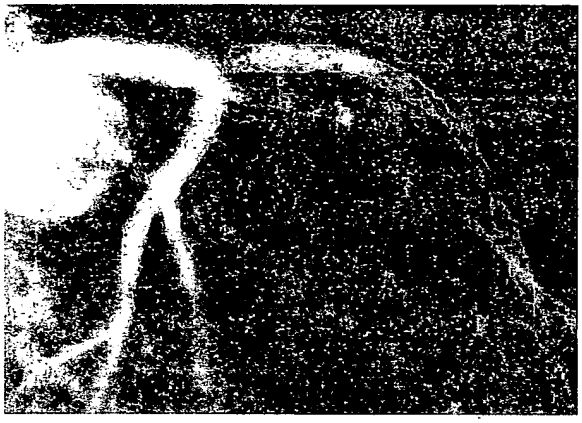


Figure 5.5: AVE 3.0 GFX stent deployed into mid-LAD.

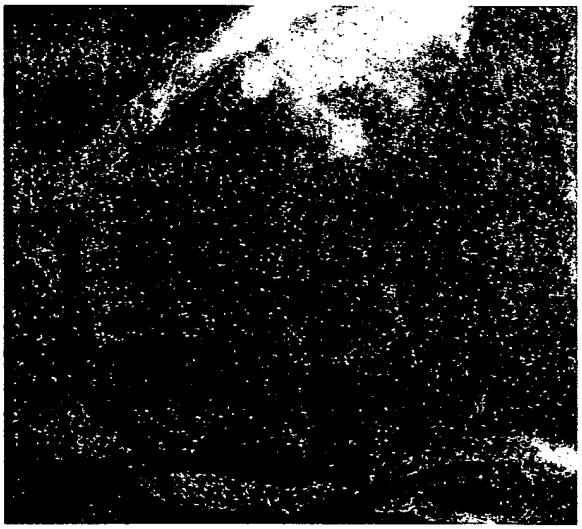


Figure 5.6: LAO 60°. RCA final after 3.5–39 and 3.5–15 mm AVE stents were deployed.

Figure 5.7: Canine experiment. A. LAD in LAO 45° 3.0–30 mm GFX stent deployment. B. Second 3.0–20 mm GFX stent is passed through the wall of first GFX stent into the diagonal branch. C. After the deployment of second stent. D. LCA in LAO 45° post-procedure.

Case 2: Patient H., 49 yr. Recent onset angina.

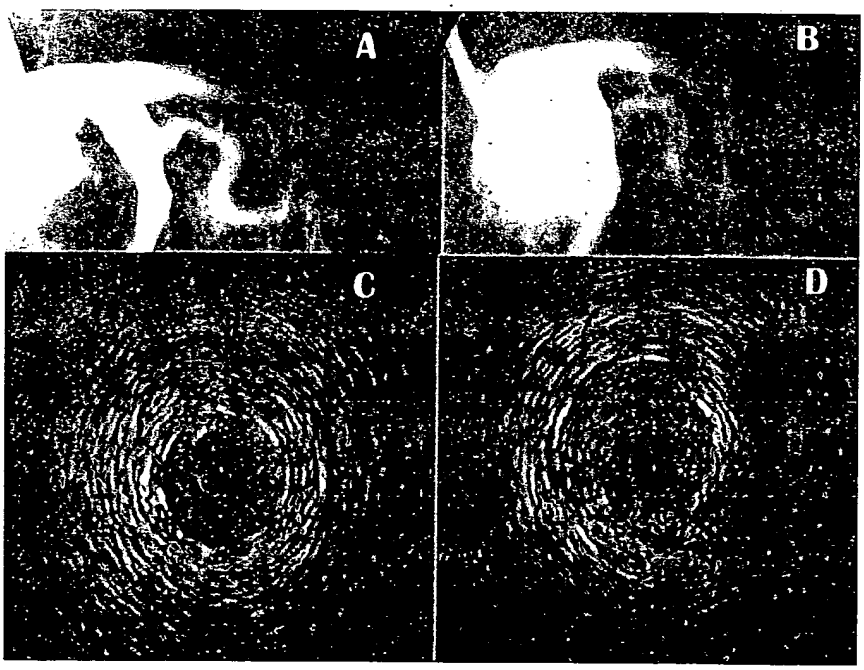


Figure 5.8: Intravascular ultrasound imaging. A. LAD RAO 30° pre-procedure. B. LAD post-deployment of two 3.5–15 mm AVE stents. C. IVUS cross-section of the distal part of the distal stent. D. IVUS cross-section of the proximal part of proximal stent.

Studies

Past

- Initial European multi-center data from Micro Stent used in a variety of complex clinical indications reported a restenosis rate of 24% after 100% angiographic follow-up in 262 patients at 6 months post-implant.
- More recent AVE Micro Stent study results by Dr Martin J. Shalij at Leiden University Hospital, The Netherlands, showed a 12% restenosis rate after a 6-month angiographic follow-up, in 65 patients.

Present

- Enrollment completed for IDE SMART study. Comparison of Micro Stent with the J&J Palmaz–Schatz coronary stent.
- STOP: Stenting of Total Occlusion versus PTCA. A multi-center study in Israel utilizing Micro Stent II to treat total occlusions.
- REFLEX GFX Study: REstenosis rate with FLEXible GFX coronary stents. A multi-center study in Germany with 6 months angiographic follow-up.
- Guermonprez/Blanchard multi-center French registry of GFX stent use.
- A number of other multi-center studies with the GFX stent are in preparation. These include studies with GFX 2.5 mm diameter stents and GFX XL (30 mm and 40 mm long) stents.

Review of published literature

1. Gaspar J, Fregoso J, Ban Hayashi E, *et al.* Clinical experience with AVE Micro Stent. Results of the implantation of 204 stents, *Archivos del Instituto de Cardiologia de Mexico* 1996; 66:476–483.

204 stents in 144 consecutive patients were deployed for acute closure in 3.4%, dissection in 5.4%, restenosis in 3.4%, non-favorable result in 16.7% and de novo in 71.1%. Angiographic lesion morphology were as follows: type A, 17.7%, type B1, 42.1%; type B2, 16.2%; type C, 24%. Procedural success 99.5% and clinical success was 93.1%. Oral anticoagulation was not routinely used. Q wave MI occurred in 0.7%, bleeding complications in 2.1%. Mortality was 0.8% in the angina group, 6.25% in the MI group. High success rates can be obtained with the AVE Micro Stent due to its excellent trackability, adequate radio-opacity and relative flexibility.

2. Rozenman Y, Lotan C, Mosseri M, *et al.* Experience with the AVE Micro stent in native coronary arteries, *Am J Cardiol* 1996; **78**:685–687.
62 AVE Micro Stents were deployed in 62 of 63 attempts (98.4%), in tortuous coronary vessels, through proximally deployed stents, and under conditions of hemodynamic instability. It is therefore a very attractive choice to treat difficult anatomy during urgent situations.

3. Köster R, Terres W, Hamm C, *et al.* Initial clinical and angiographic results with the AVE Micro Stent, *Z Kardiol* 1996; **85**:640–646.
105 AVE Micro Stents were deployed in 78 lesions in 64 patients electively (19%), after unsatisfactory PTCA (59%), and as 'bailout' (23%) into left main (1), LAD (23), LCX (15), RCA (19) or CABG (6). Deployment was successful in 62 of 64 patients. The passage through previously deployed stents (46) was successful in all of 28 cases. There were no deaths or myocardial infarctions. In two patients, subacute thromboses occurred. The AVE Micro Stent can be safely and efficiently deployed even through implanted stents. It appears to be particularly suitable for 'bailout' therapy of dissections.

4. Ozaki Y, Keane D, Ruygrok P, *et al.* Acute clinical and angiographic results with the new AVE Micro Coronary Stent in bailout management, *Am J Cardiol* 1995; **76**:112–116.
Twenty-eight AVE Micro stents were deployed in 23 lesions in 20 patients with acute or threatened closure after PTCA. Stent deployment was successful in 27 of 28 attempts (96%). A myocardial infarction was observed in two patients (10%). No subacute occlusion was observed. Event-free survival at 30 days after stent implantation was 85% (17 of 20 patients).

5. Markert T, Bertsch G, Langenfeld H, *et al.* Elective coronary implantation of a newly developed stent without conventional anticoagulation, *Dtsch Med Wochenschr* 1996; **121**:1213–1219.
AVE Micro Stents were implanted into 128 vessels in 121 patients with a complex stenosis morphology or unfavourable short- and long-term prognosis. The primary success rate of stent implantation was 99%. Neither acute nor subacute thromboses were reported. There was no bypass surgery or early PTCA. There were no abnormal bleedings. Lesions unsuitable for conventional PTCA can be reliably treated with the AVE Micro Stent. Optimal high-pressure dilatation in combination with dual anti-aggregation treatment prevents stent thrombosis and bleeding complications.

6. Dittel M, Prachar H, Spiel, R *et al.* Incidence and management of acute left main coronary artery dissection as a complication of acute transluminal coronary angioplasty, *Z Kardiol* 1996; 85:635–639.
7. Ghannem M, Lefevre T, Bernard A *et al.*, Restenosis on coronary endoprosthesis: treatment by implantation of a new endoprosthesis. Apropos of a case, *Ann Cardiol Angiol* 1996; 45:287–290. These last two articles report the use of AVE Micro Stents for the emergency treatment of left main coronary artery dissections complicating PTCA.

6. The Multilink Coronary Stent System

Guidant/Advanced Cardiovascular Systems, Santa Clara, CA, USA

Wim J van der Giessen and Susan Veldhof

Description	• Balloon expandable stent • Tubular design • Multiple rings connected with multiple links

History	• 1993 first clinical experience reported by Ulrich Sigwart • 1994 first multi-centre registry study started • 1995 clinical use in Europe, Canada and Asia/Pacific • 1996 approved in Japan

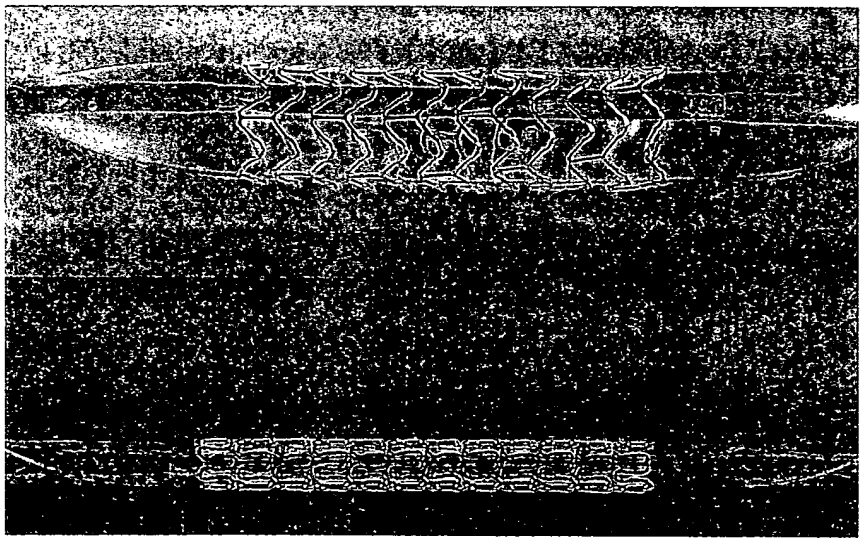


Figure 6.1: The Multilink stent is a balloon expandable stent. It has a tubular design, with multiple rings connected with multiple links to enhance hoop strength, while allowing sufficient longitudinal flexibility.

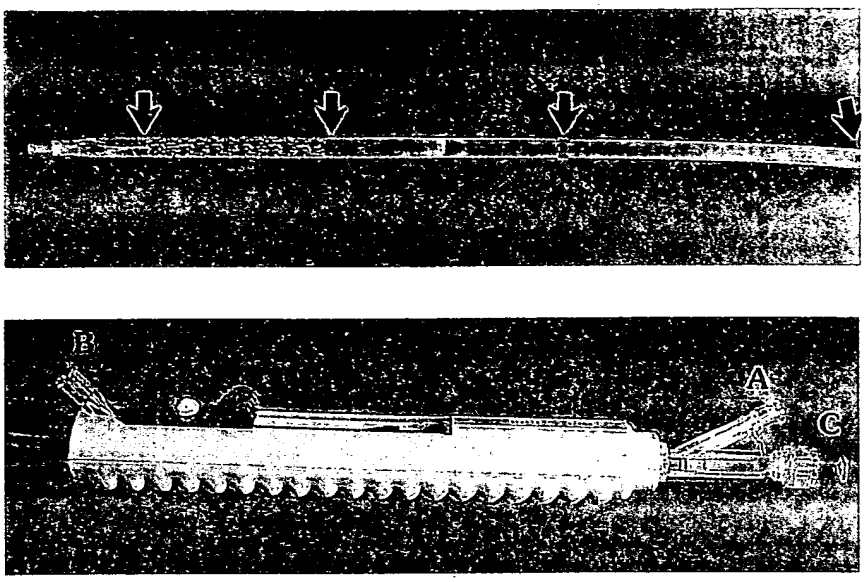
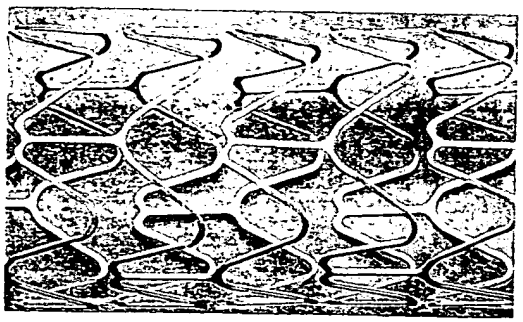


Figure 6.2: Four different delivery systems are currently available:

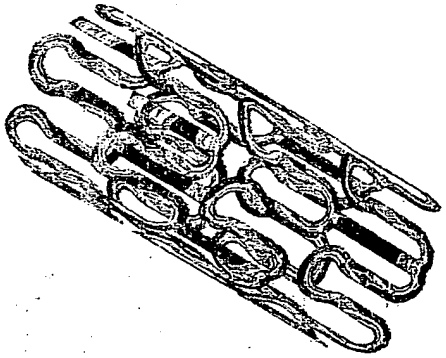
- a rapid exchange delivery system: ACS RX Multilink™ coronary stent system (see Figure 6.1).
- a rapid exchange high pressure delivery system: ACS RX Multilink™ HP coronary stent system.
- an over-the-wire delivery system: ACS Multilink™ coronary stent system (see Figure 6.2).
- an over-the-wire high pressure delivery system: ACS Multilink™ HP coronary stent system.

These proprietary delivery systems have the stent factory-crimped onto specially folded balloons (propellor-folded) wrapped in an elastic membrane to offer three key advantages:

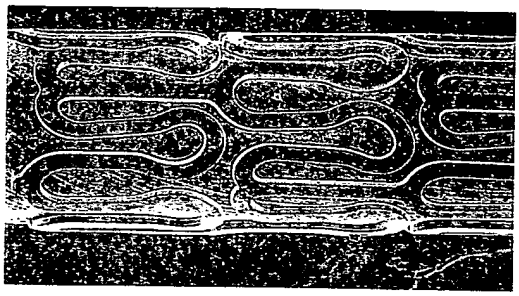
- even distribution of inflation force for concentric stent expansion and optimal strut apposition to the artery wall;
- streamlined balloon refold with rapid deflation times post-stent deployment;
- reliable crimping of the stent on the balloon to guard against stent loss.



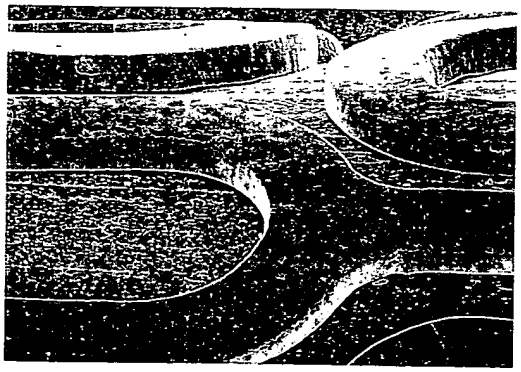
a



b



c



d

Figure 6.3: a. Detail of Multilink stent showing the specific design of the rings and links. b. The Multilink design incorporates more metal at the sites where more stress is applied to the stent, because of the continuing pressure fluctuations during millions of cardiac cycles. Computer aided technique and finite element analysis have been extensively used throughout the development of the ACS Multilink stent, in order to ensure ideal expansion, structural integrity and long term durability. c. Detail of the stent crimped onto the delivery balloon (scanning EM, magnification 40×). d. At higher magnification (SEM, 300×) the smooth surface of the individual struts can be appreciated.

Multilink™ stent technical specifications

Material composition:	316L stainless steel
Degree of radio-opacity (grade):	Moderate/low
Ferromagnetism:	Non-ferromagnetic (MRI safe)
Metallic surface area (expanded):	15% average, metal:artery
Stent design:	Corrugated rings interconnected by multiple links. Each set of rings is connected by three links. Forms a series of 'S', 'W' and 'U' shapes
Strut design:	Tubular multiple rings connected with multiple links
Strut thickness	0.002 inch (0.05 mm)
Profiles:	
Non-expanded (uncrimped)	RX 4.3F RXHP 4.3F OTW: 4.1F with sleeve retracted, 5.0F with sleeve (5.7F: 4.0 mm) OTW HP: 4.5F
Longitudinal flexibility:	High
Percentage shortening on expansion:	2.7% (3.0 mm size)
Degree of recoil (shape memory):	4.8% (3.0 mm)
Radial force:	Excellent; full collapse at 15.6 psi (3.0 mm)
Currently available diameters:	2.5/3.0/3.25/3.5/3.75/4.0 mm
Currently available lengths:	
Mounted	RX: 15/25/35 mm RX HP: 15 mm OTW and OTW HP: 15 mm
Unmounted	None
Currently available sizes:	RX: 2.5, 3.0, 3.5, 4.0 mm OTW: 3.0, 3.25, 3.5, 3.75, 4.0 mm
Expansion range:	4.1 mm (maximum expansion)
Recrossability of implanted stent:	Excellent
Other non-coronary types available:	No

Stent delivery system

RX Multilink™
RX Multilink HP™
OTW Multilink™
OTW Multilink HP™

Mechanism of deployment:	Balloon expandable
Mechanism of expanding:	Propeller folded balloon wrapped in an elastic membrane to distribute even inflation force for strut apposition to the artery wall and concentric expansion
Minimal internal diameter of guiding catheter:	RX 15 mm all sizes: 0.064 inch (1.6 mm) (4.0 mm: 0.072 inch, 1.8 mm) RX 25 mm all sizes: 0.072 inch (1.8 mm) (4.0 mm: 0.082 inch, 2.1 mm) RX 35 mm all sizes: 0.082 inch (2.1 mm) RX HP 15 mm all sizes: 0.064 inch (1.6 mm) OTW 15 mm all sizes: 0.075 inch (1.9 mm) (3.75 and 4.0 mm: 0.082 inch, 2.1 mm) OTW HP 15 mm all sizes: 0.064 inch (1.6 mm)
Monorail system:	Yes
Balloon characteristics:	Propeller fold with elastic membrane
Balloon material:	RX and OTW: PE 600® RX HP and OTW HP: P-FLEX PLUS™
Minimum recommended guide:	0.014 inch (0.36 mm)
Pre-mounted on delivery catheter:	Yes
Pre-mounted on a high pressure balloon:	Yes
Protective sheath/cover:	Yes: OTW only (not OTW HP)
Offered as a bare stent:	No
Position of radio-opaque markers:	Proximal and distal to stent
Rated burst pressure of balloon:	RX 15 mm all sizes: 8 atmospheres (4.0 mm: 6 atmospheres) RX 25 mm all sizes: 8 atmospheres (4.0 mm: 7 atmospheres) RX 35 mm all sizes: 8 atmospheres (4.0 mm: 7 atmospheres) RXHP 15 mm all sizes: 16 atmospheres (4.0 mm: 15 atmospheres) OTW 15 mm all sizes: 10 atmospheres OTW HP 15 mm all sizes: 16 atmospheres (4.0 mm: 15 atmospheres)

Stent delivery system – *continued*

Delivery balloon compliance:	Low
Delivery profile:	RX: 0.058–0.063 inch (1.5–1.6 mm) RX HP: 0.054–0.055 inch (1.4 mm) OTW: 0.068–0.078 inch (1.7–2.0 mm) OTW HP: 0.058–0.059 inch (1.5 mm)
Longitudinal flexibility:	Excellent
Recommended deployment pressure:	RX 15 mm all sizes: 6 atmospheres RX 25 mm and 35 mm all sizes: 7 atmospheres (4.0 mm: 10 atmospheres) OTW 15 mm all sizes: 9 atmospheres OTW HP all sizes: 11 atmospheres (4.0 mm: 10 atmospheres)
Further balloon expansion recommended:	At physician's discretion, depending on lesion characteristics
Further dilatation recommended:	At physician's discretion, depending on lesion characteristics
Balloon dilatation and stent sizing:	Equal to artery or oversizing up to 10%
Recrossability of implanted stent (Grade):	Very good
Sizing diameter:	Equal to artery or oversizing up to 10%

Current indications for clinical use

- Native coronary arteries, de novo and restenotic lesions

New product developments

- SOLO Stent
- DUET Stent system
- A new platform of both mounted and unmounted stents for native vessels and saphenous vein grafts.
- To be available in four lengths

On-going or planned trials

Name	*Number of patients*	*Type*	*Total number of sites*	*Status/ follow-up*	*Results*
WEST 1	102	Registry Full anticoagulation	7 all in Europe	Complete/ 1 year data available	Target lesion restenosis: 12% Target vessel restenosis: 5% 30 day MACE: 5.9% 6 month MACE: 17.6% 1 year MACE: 18.8%
WEST 2	165	Registry On line IVUS and QCA ASA only	17 in Europe and 1 New Zealand	Complete/ 6 Month data available	SAT rate: 1.2% 30 day MACE 1.8% 6 month MACE: 9.1% Restenosis rate 12.9% (138 patients in database)
ASCENT	1040	Randomized Multilink vs Palmaz-Schatz. ASA and Ticlid De novo lesions	59 all in North America	Complete/ clinical and 9 month angiographic data available	9 month in-stent restenosis rate 15.5% for Multi-Link vs 19.6% for JJIS 6 month target vessel failure rate of 14.6% for ML vs 17.1% for JJIS SAT rate 0.6% for ML vs 1.9% for JJIS

On-going or planned trials – *continued*

Name	*Number of patients*	*Type*	*Total number of sites*	*Status/ follow-up*	*Results*
ASCENT Restenosis Registry	201	Registry, restenotic lesions	59 all in North America	6 month clinical follow-up complete	6 month target failure rate of 12.9%
High ASCENT	101	Registry using RX HP Multi-link system	11 all in United States	In progress	78% of patients post dilated successfully Patients discharged from hospital significantly sooner than ASCENT patients, 1.29 vs 1.64 days. 30 day MACE: 2.0%
Long ASCENT	202	Registry using 15 mm, 25 mm and 35 mm RX Multilink systems	18 all in United States	In progress	25 mm long, stent patients discharged from hospital significantly sooner than 2 × 15 mm long patients, 1.06 vs 1.64 days
IVUS	49	Registry with IVUS	3 all in US	Complete/ 12 month data available	Analysis ongoing
Japan	1123	Registry	2 in Japan	Complete/ 6 month clinical and angiographic data available	In stent restenosis 14%
STELLA	120	Registry using RX 25 and 35 mm lengths 2 week Ticlid only	5 in Australia 4 in New Zealand 1 in Canada	In progress	
CADILLAC	1600	Randomized stenting vs PTCA in AMI with Rheopro	>40 in US 7 in Europe	In progress	

On-going or planned trials – *continued*

Name	*Number of patients*	*Type*	*Total number of sites*	*Status/ follow-up*	*Results*
SOS	1000	Randomized stenting vs CABG in Multivessel disease	47 sites, all in Europe	In progress	
SMILE	100	Registry, stents in long lesions	10 sites, all in Europe	In progress	
Bifurcation	100	Registry, stents in bifurcation lesions	10 sites, all in Europe	In progress	

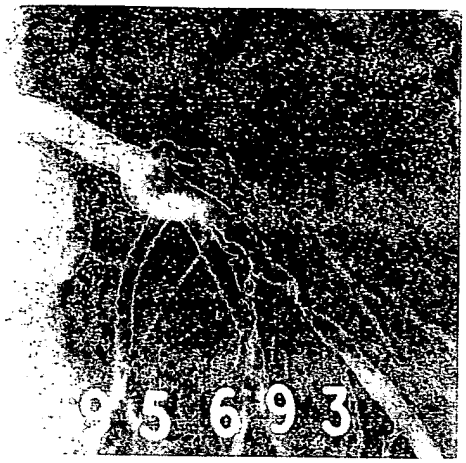


Figure 6.4: An eccentric stenotic lesion is seen in the mid anterior descending coronary artery in a 47-year-old male with stable angina pectoris.

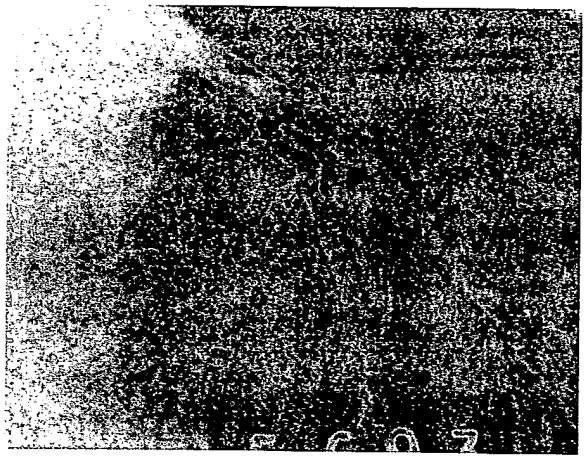


Figure 6.5: The same lesion as in Figure 6.4 after predilation with a 3.0 mm compliant balloon.

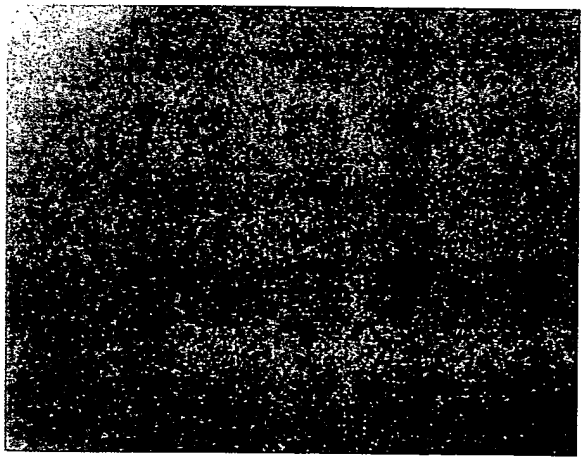


Figure 6.6: Shows deployment of a 3.5-mm Multilink stent system at 10 atmospheres.

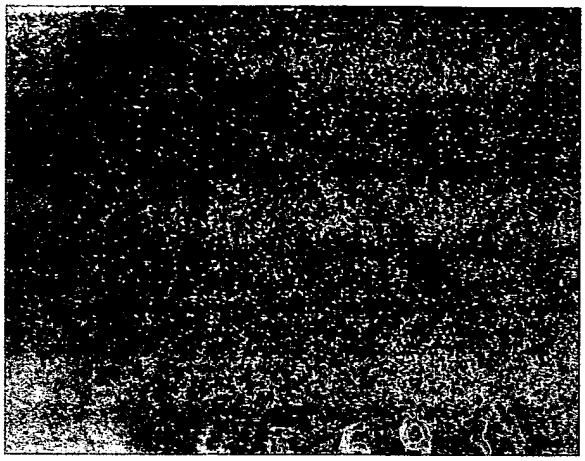


Figure 6.7: The final result following post-dilatation with a 3.5 mm non-compliant balloon at 18 atmospheres.

Figure 6.8: At 6-month follow-up the stented LAD is clear.

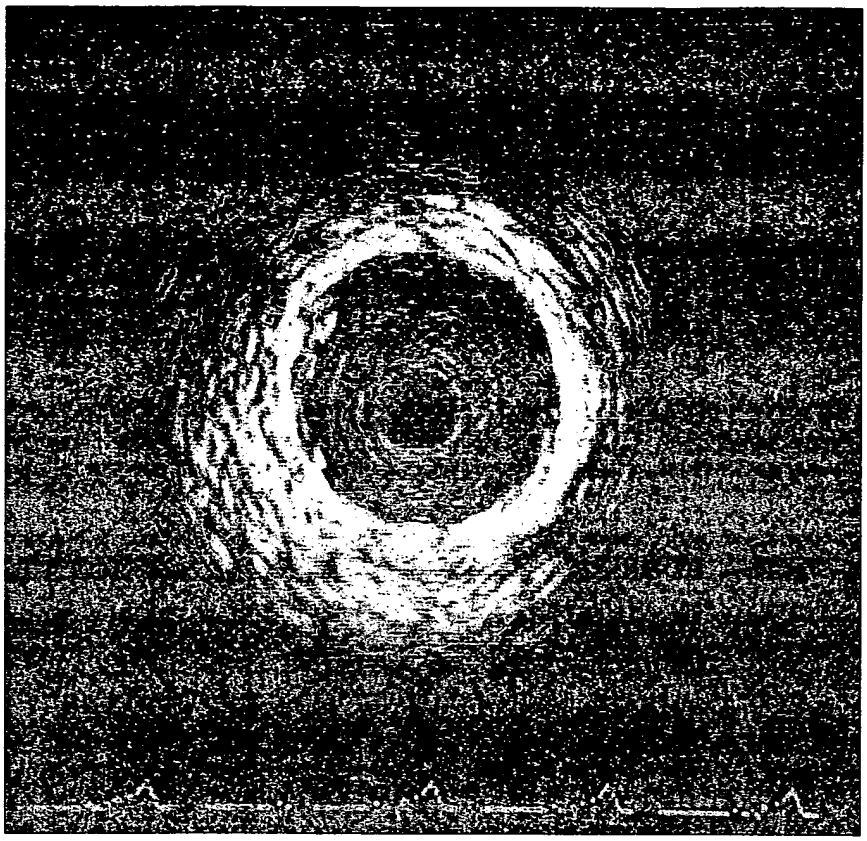
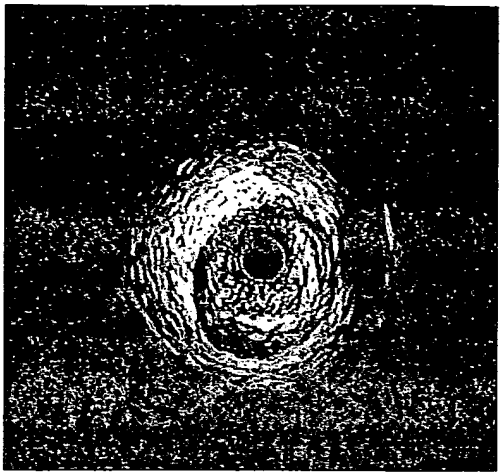
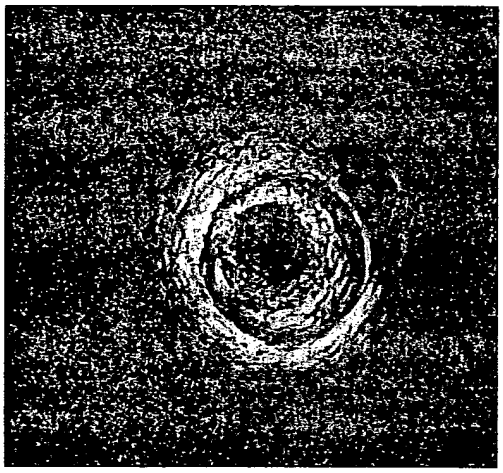


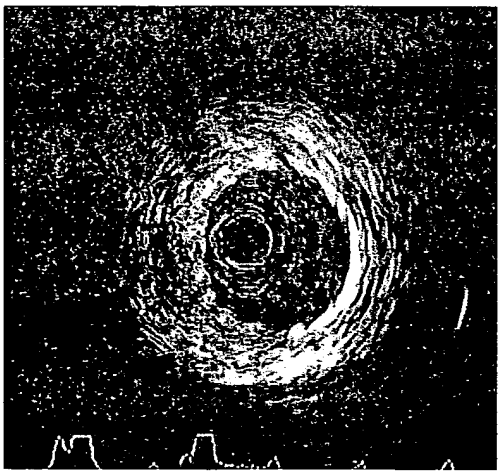
Figure 6.9: *The Multilink stent can be easily and safely recrossed for intravascular ultrasound guidance. Here the final acute result of this case shows good apposition and a nicely circular lumen.*



a



b



c

Figure 6.10:
a. Intravascular ultrasound recording of a tight LAD lesion in a 55-year-old male with unstable angina. b. After balloon dilatation with 3.0 mm balloon there was some improvement but considerable recoil. c. After implantation of a 3.5 mm Multilink stent and high-pressure inflation up to 18 atmospheres a considerably larger lumen has been obtained.

The Multilink coronary stent system

Advantages	*Disadvantages*
• Strength and flexibility combined	• Moderate visibility
• Trackable	
• Push enhancing retractable protective sleeve (only over-the-wire·ACS Multilink™ coronary stent system)	
• Sleeveless, rapid-exchange version 6 Fr guiding catheter compatible	
• Elastomeric sheath over balloon to ensure radial concentric stent expansion	
• Stent symmetrical on intravascular ultrasound following deployment	
• Suitable branch access	
• Safe and accurate delivery	

References

1. Rogers C, Edelman E. Endovascular stent design dictates experimental restenosis and thrombosis. *Circulation* 1995; 91:2995–3001.
2. Priestley KA, Clague JA, Buller NP, *et al.* First clinical experience with a new, flexible, low profile metallic stent and delivery system. *Eur Heart J* 1996; 17:438–444.
3. Wong P, Wong CM, Chang CH, *et al.* Early clinical experience with the Multi-Link coronary stent. *Cathet Cardiovasc Diagn* 1996; 39:413–419.
4. Clague JR, Arvinder S, Kurbaan MB, *et al.* The new ACS Multilink coronary stent: a single centre experience in 103 consecutive patients with and without oral anticoagulation. *J Intervent Cardiol* 1997; in press.

Abstracts

AHA1995

Dawkins KD, Emanuelsson H, van de Giessen W, *et al.* Preliminary results of a European multicentre feasibility and safety registry on an innovative stent. The WEST study. *Circulation* 1995; 92(Suppl I):I-280.

ESC 1996

van der Giessen W, Emanuelsson H, Dawkins K, *et al.* Six month clinical outcome and angiographic follow up of the WEST study. *Eur Heart J* 1996; 17: (Abstr Suppl):411.

Chevalier B, Royer T, Guerin Y, *et al.* Early clinical experience of coronary stenting with the Multi-Link stent. *Eur Heart J* 1996; 17: (Abstr Suppl):179.

Anzai H, Nakamura S, Nishida T, *et al.* Comparison of radial force of Palmaz Schatz stent, Multi-Link stent and Act One stent by intravascular ultrasound. *Eur Heart J* 1996; 17: (Abstr Suppl):158.

AHA 1996

Waigand J, Uhlich F, Gulba DC, *et al.* Intra coronary stenting with the Multi-Link stent-single centre experience. *Circulation* 1996; 94: (Suppl I):I-88.

Carrozza JP, Yock PG, Linnemeier TJ, *et al.* Serial expansion of the ACS Multi-Link stent after 8, 12 and 16 atmospheres. A QCA and IVUS pilot study. *Circulation* 1996; 94: (Suppl I):I-88.

Hermiller JB, Baim DS, Linnemeier TJ, *et al.* Clinical results with the ACS Multi-Link stent in the US pilot phase. *Circulation* 1996; 94: (Suppl I):I-88.

Chevalier B, Royer T, Glatt B, *et al.* Early clinical experience with the Multi-Link coronary stent. *Circulation* 1996; 94: (Suppl I):I-88.

ACC 1997

Honda Y, Yock CA, Hermiller JB, *et al.* for the Multi-Link Investigators Longitudinal redistribution of plaque is an important mechanism for luminal expansion in stenting. *J Am Coll Cardiol* 1997; 29(Suppl A): 218A.

Poerner T, Voelker W, Teubner J, *et al.* Effect of high pressure balloon dilatation upon the deployment of different coronary stents — an in-vitro study using direct magnification radiography. *J Am Coll Cardiol* 1997; 29(Suppl A): 274A.

Pomeranstev EV, Juergens CP, Whitbourn RJ, *et al.* QCA Comparison of J&JIS, Cook, Flexstent, AVE Micro Stent and ACS Multi-Link Stents. *J Am Coll Cardiol* 1997; 29(Suppl A): 494A.

Calver AL, Dawkins KD, Haywood GA, *et al.* Multi-Link stenting, a 'minimalist' approach using Aspirin alone — no Ticlopidine, no Coumadin, no IVUS and no QCA. *J Am Coll Cardiol* 1997; 29(Suppl A): 95A.

Klues HG, Schwarz ER, vom Dahl J, *et al.* Intracoronary stent implantation — a new therapeutic approach in highly symptomatic patients with myocardial bridging. *J Am Coll Cardiol* 1997; 29(Suppl A): 220A.

The Publishers would like to thank Guidant/Advanced Cardiovascular Systems for their support

GUIDANT
VASCULAR INTERVENTION

14. THE NIR STENT, TRANSFORMING GEOMETRY

Medinol Ltd, Tel Aviv, Israel

Kobi Richter, Yaron Almagor and Martin Leon

Description

General

The NIR Stent was developed based on many physicians' 'wish list' for new functional features in order to overcome shortcomings of first generation devices. The two most important features of the coronary stent are basic to its use: the radial force with which it supports the vessel, and its flexibility, one of the major determinants of its trackability into the target lesion before deployment. The basic contradiction between flexible structure that enable good trackability and rigid structure that result in optimal support, brought the developers of first generation stents to select one property while compromising on the other. A typical comparison of features resulting from that forced decision is:

Stent	Radial support	Flexibility
Palmaz–Schatz	High	Low
Gianturco–Roubin	Low	High

Our primary goal in designing the NIR Stent was to overcome this compromise by a new design for the stent, with a secondary goal to optimize other clinically important features.

Transforming geometry

A design goal was defined noticing that the two features are not required simultaneously, but rather at two mutually exclusive time slices.

- Flexibility is required only during insertion and until deployment of the stent at the target lesion.
- Rigidity is required to supply long term support to the vessel wall only from the moment of deployment and on.

It was thus defined that the desired geometry should be flexible upon insertion and will change after deployment to be rigid upon expansion.

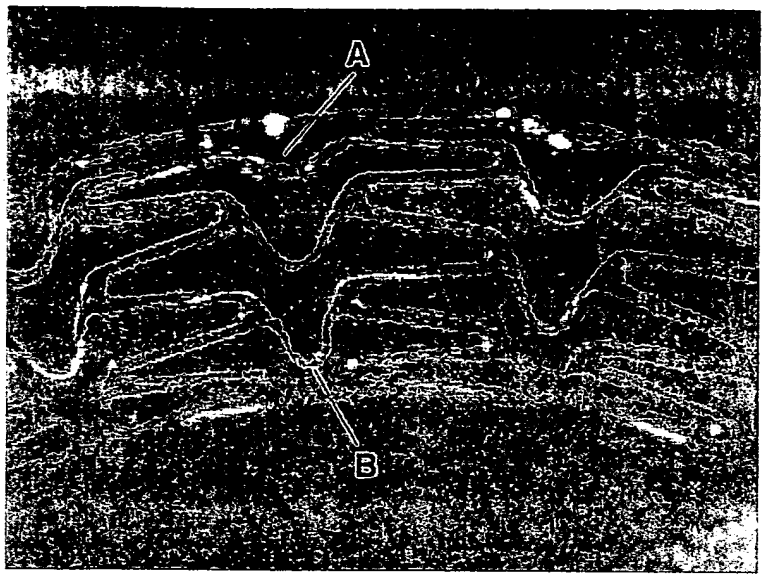


Figure 14.1: The NIR stent before expansion, showing the differentially elongating cells. The cell inside the curve is shorter than its counterpart outside the curve, as shown by the converging lines at their border. This feature is enabled by the vertical loop component of the cell that opens on the outside cell (A) and closes on the inside cell (B).

Trackability and flexibility

The flexibility of a stent, a long stent especially, is a major parameter in determining its trackability into the naturally curved and tortuous anatomy of diseased coronary arteries. In order to track into such anatomies the stent on its delivery system has to curve around corners or it will latch on the opposing vessel wall. The flexibility depends on the ability of the stent to elongate differentially such that the stent wall outside of the curve be longer than the wall inside the curve. Inability or high resistance to such differential elongation will not allow the stent to flex. The design of the NIR stent is based on uniform cells each of which is capable of elongating or foreshortening as demonstrated in Figure 14.1.

Other important features that facilitate the trackability of the stent are:

1. The stent has no 'free internal points' loops or ends internal to the tubular structure that are not connected longitudinally to their neighbors and thus can flare out and generate internal ridges that will latch on plaque surface upon insertion (Figure 14.2).
2. The stent has a very low profile and crimps easily and securely on the balloon

owing to the original structure with struts slightly open (see Figure 14.1) that leaves a lot of room for crimping until struts touch each other (see Figure 14.2).

3. Most of the struts are along the insertion direction of the stent and thus will not catch on plaque the way a typical coiled stent would (see Figure 14.2).

NIR stent technical specifications

Material composition:	Stainless steel
Degree of radio-opacity:	Moderate
Ferromagnetism:	None
Metallic area (expanded state)	11–18%
Metallic recoil:	<1%
Strut design:	Square, transform from flexible to rigid
Strut thickness:	0.1 mm (0.004 inch)
Non-expanded profile:	≤1.0 mm (<0.04 inch)
Longitudinal flexibility:	Excellent upon insertion, low after expansion
Percentage shortening on expansion:	<3%
Available expanded diameters:	2–5 mm
Lengths:	9, 16, 25 and 32 mm
Other non-coronary types available:	Peripheral stents for peripheral vessels, biliary, renal and other uses: lengths: 14, 19, 39 and 59 mm. Expanded diameter range: 5–12 mm

NIR stent delivery system

Mechanism of deployment:	Balloon expandable
Minimal internal diameter of guiding catheter:	1.6 mm (0.064 inch)
Premounted on delivery catheter:	Yes, available also as bare stent
Protective sheath/cover:	No
Position radio-opaque markers:	On both ends of the stent
Further balloon expansion recommended:	No
Recrossability of implanted stents:	Excellent
Sizing diameter:	Matching target vessel diameter

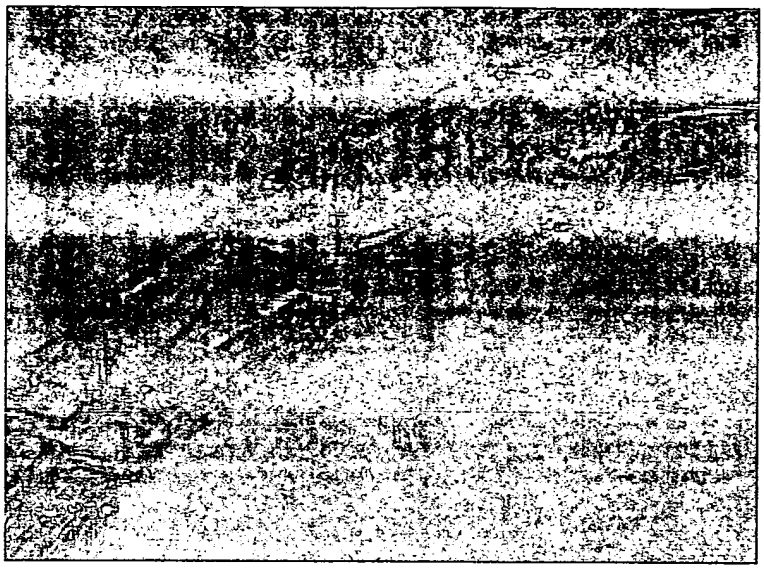


Figure 14.2: The crimped NIR stent, showing a low profile of less than 1.0 mm and a smooth surface with no internal flare-out points at the outside of a curved section. Notice also the difference between the slightly open struts of Figure 14.1 and the tightly crimped struts at this figure.

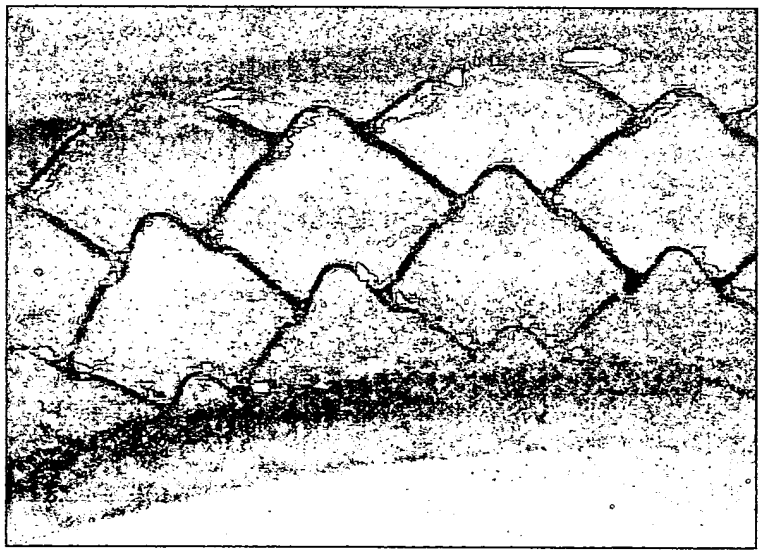


Figure 14.3: The expanded NIR stent, showing uniform cells in which the vertical loop struts have aligned with the horizontal loop struts to form straight struts. The resulting structure is a very rigid and strong structure.

Rigidity and radial support

During expansion of the stent in the target lesion the geometry of the basic uniform cell changes (Figure 14.3) in a way that will cause the vertical loops of the cell to align with the horizontal loops and form a diamond-like cell with straight struts at about 45°.

The resulting diamond-like mesh with interlinked struts is much stronger and more rigid than any structure without such interlinking. At this point in time the stent loses its flexibility, but this lost feature is no longer important since the stent is not required to move anywhere.

Important features of the expanded NIR stent

1. The uniform cellular design allows for a continuous support without gaps unlike articulations in other stents, or increased distance between struts that may occur in stents whose struts are not interlinked and move relative to each other.
2. The relatively small cells decreased the chance for tissue prolapse and plaque scale protrusion into the lumen. The smaller cells made of shorter struts provide for higher radial resistance and decreased wall trauma by decreasing the local pressure on the wall. The number of circumferential struts in the NIR stent is 18 and in the Palmaz–Schatz 8, thus at an equal total radial force the local force applied by each strut is less than one half in the NIR stent.
3. The differential elongation of the vertical loops of the cells, responsible for the flexibility upon insertion, allows for conformance of the stent with the vessel curvature such that the rigid expanded stent does not straighten the vessel and does not create a sharp kink at the interface between the stented area and the unstented area. Such a kink created by other rigid stents (e.g. Palmaz–Schatz may cause turbulence and applies excessive local pressure that accounts for a higher restenosis rate at the stent ends. That feature of conformance with vessel curvature (see Figure 14.3) allows also for multiple stenting of long segments required in many cases of diffuse disease and generates a smooth conformed reconstructed section.
4. All stents available on the market foreshorten upon expansion by varied amounts owing to the change in diameter of the stent. The combination of vertical loops and horizontal loops in the NIR cell results in minimized foreshortening based on the fact that upon expansion the horizontal loops foreshorten but the vertical loops elongate and compensate for the foreshortening thus keeping the total length of the cell unchanged (Figure 14.4).

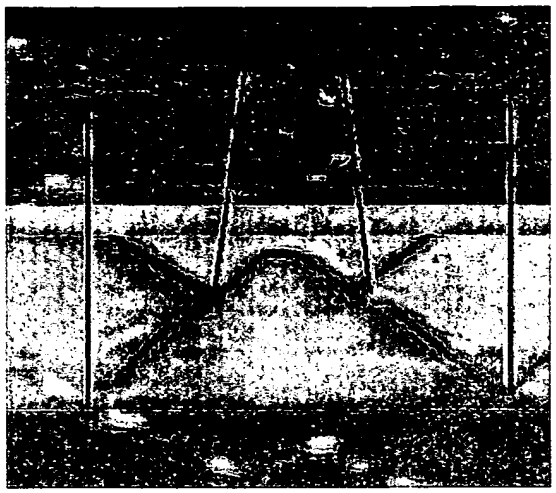


Figure 14.4: While the cell expands the horizontal loops foreshorten and the vertical loops elongate to leave the total length of the cell unchanged.

Case examples

The following are examples of cases treated with the NIR stent. The cases are from the first pilot study performed in the Centro Cuore in Milan on July 1995, by Drs Colombo, Almagor and DiMario.

Case 1:

A diffuse lesion in the LAD was treated by two, slightly overlapping stents (Figure 14.5), to yield a good result in the LAD, but leaving a tight lesion at the diagonal.

The insertion of an Ace balloon through the struts into the diagonal (Figure 14.6) demonstrates the accessibility of side branches after stenting. Notice also the conformance of the stent to the curve, and the sharp definition of vessel

Figure 14.5: Two 32-mm NIR stents were inserted to yield a nice result in the LAD but a tight lesion at the first diagonal.

Figure 14.6: Following the insertion of an Ace 2.5-mm balloon through the expanded cells, and the expansion of the Ace with a balloon at the LAD (left panel), the final result is an open diagonal and open LAD.

contour demonstrating radial strength and continuous support typical of the NIR stent angiographic results.

Case 2:

A 32-mm stent was inserted into a very tortuous RCA using a right Judkins guiding catheter. In spite of the suboptimal support the stent tracked into the vessel smoothly to yield a good result in a very short procedure involving a single stent.

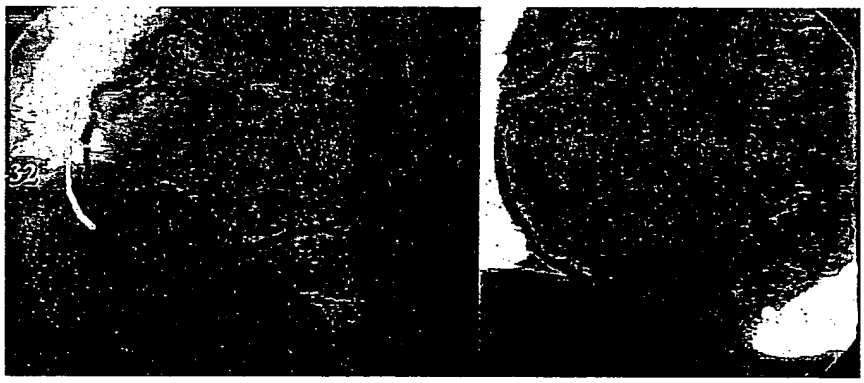


Figure 14.7: A 32-mm NIR stent was inserted into a very tortuous RCA, demonstrating the trackability of the stent. The result on the right would require at least two stents of other designs.

Conclusion

The NIR stent is a second generation stent with improved functional features, as demonstrated by its geometry and the case results.

NIROYAL™ stent technical specifications	
Material composition:	Stainless steel plated with gold
Degree of radio-opacity:	Excellent
Ferromagnetism:	None
Metallic area (expanded state):	11–18%
Metallic recoil:	<0.5%
Strut design:	Rounded square, transforms from flexible to rigid upon expansion
Strut thickness:	0.1 mm (0.004 inch)
Non-expanded profile:	< 1.0 mm (0.04 inch)
Longitudinal flexibility:	Excellent upon insertion, reduced after expansion
Percentage shortening:	<3%
Available expanded diameter:	2–5 mm
Lengths:	9, 16, 25, 32 mm
Other non-coronary types available:	Peripheral stents length: 14, 19, 39, 59 mm, diameter 5–12 mm

New features available

Two main new features have been introduced to the coronary market since the first edition. A pre-mounted system and the NIROYAL gold plated radio-opaque stent. The pre-mounted system, the NIR PRIMO™, features the NIR™ PRIMO™ stent pre-mounted on a modified VIVA PRIMO™ balloon catheter from SciMED. The pre-mounted system saves time as crimping is not required and increases safety by a better and more consistent crimping. The system also features a short ring of plastic material inserted under the balloon in front of the stent. This increases the diameter of the balloon in front of the stent and creates a 'dam' that prevents the stent from slipping off the balloon (see Figure 14.8).

The NIROYAL stent is a NIR stent plated with gold (see Figure 14.9) to increase its radio-opacity. The stent has indeed a drastically improved radio-opacity (see Figure 14.10) that allows its visualization before and after expansion. The radio-opacity of the NIROYAL was, nevertheless, designed such that the stent will be visible but will not hide angiographic details after its deployment (see Figures 14.11–14.18). The radio-opacity of the NIROYAL is important for positioning judgment by the physician, and especially in cases of multiple stents for judgment of overlap, and in bifurcation and ostial stenting where relative position is critical.

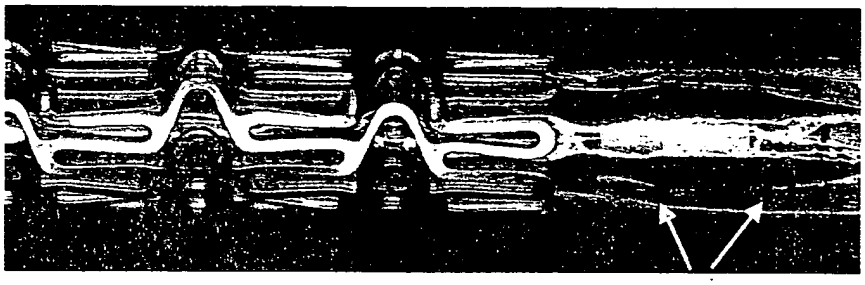


Figure 14.8: The distal tip of the stent premounted on a balloon, showing the 'Dam' (arrows).

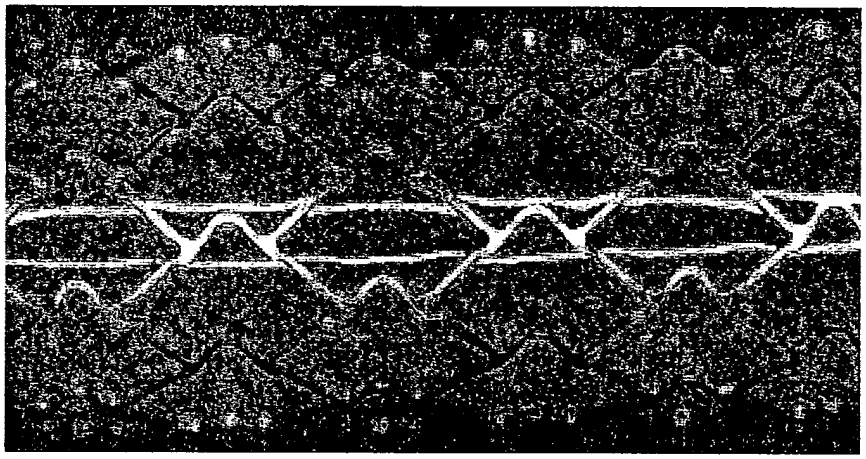


Figure 14.9: The NIROYAL stent after expansion.

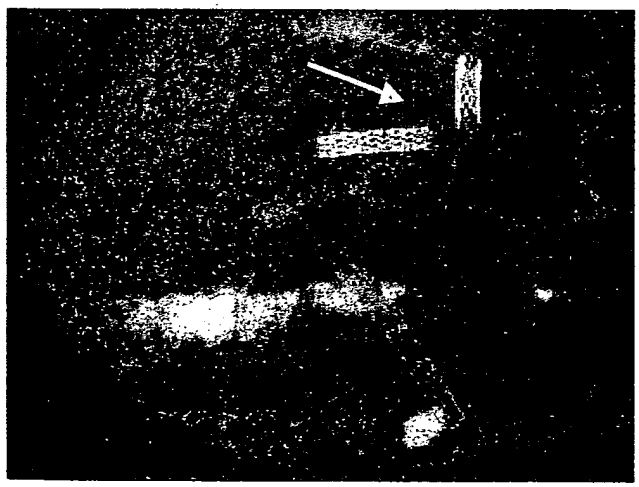


Figure 14.10: An X-ray radiograph of an excised porcine heart shows the excellent radio-opacity of the NIROYAL stents (yellow arrow), as compared to the regular NIR stent (red arrow).

Case examples

The following are examples of cases treated with new NIR stents. The first one is a case of a bifurcation stenting performed with the NIROYAL, and the second is a renal case performed with a peripheral NIR.

Case 1:

A lesion in the LAD involving an ostial lesion in the first diagonal was selected for treatment (Figure 14.11). A 32 mm long NIROYAL was placed in the LAD across the bifurcation of the diagonal (Figures 14.12 and 14.13). A second, 9 mm long NIROYAL was inserted into the diagonal through the cells of the LAD stent (Figures 14.14 and 14.15). The diagonal stent left a gap at the ostium uncovered (Figure 14.16) and a third NIROYAL was placed to bridge the gap (Figure 14.17) to yield a good final result (Figure 14.18).

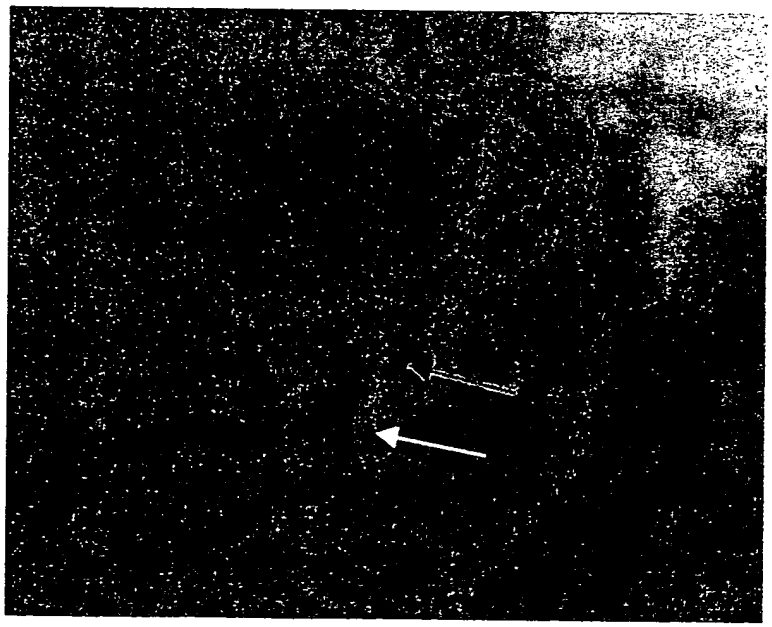


Figure 14.11: A lesion in the LAD (red arrow) overlaps an ostial lesion in the diagonal (yellow arrow).

Figure 14.12: The 32 mm NIROYAL is placed in the LAD showing its radiopacity.

Figure 14.13: The NIROYAL expanded in the LAD

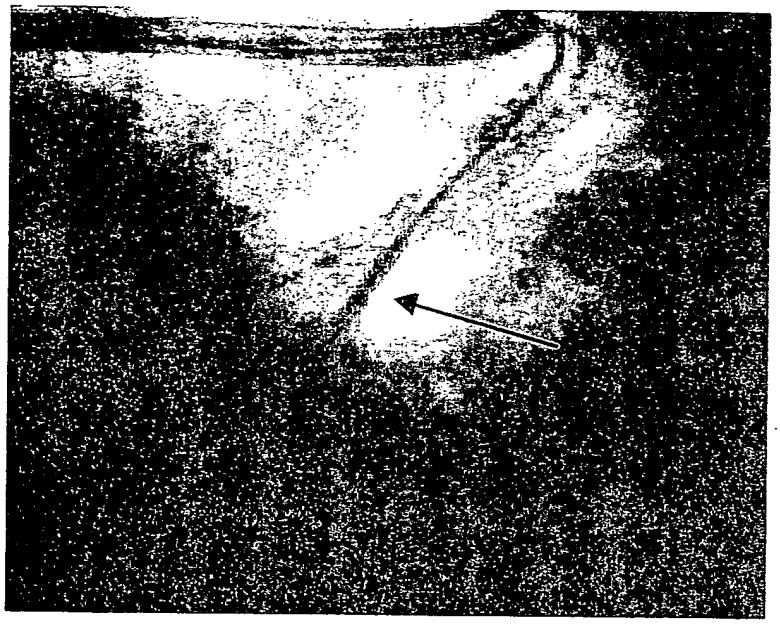


Figure 14.14: *The short NIROYAL (arrow) is placed in the diagonal through the struts of the expanded stent.*

Figure 14.15: *The second stent is deployed using 'kissing balloons' technique.*

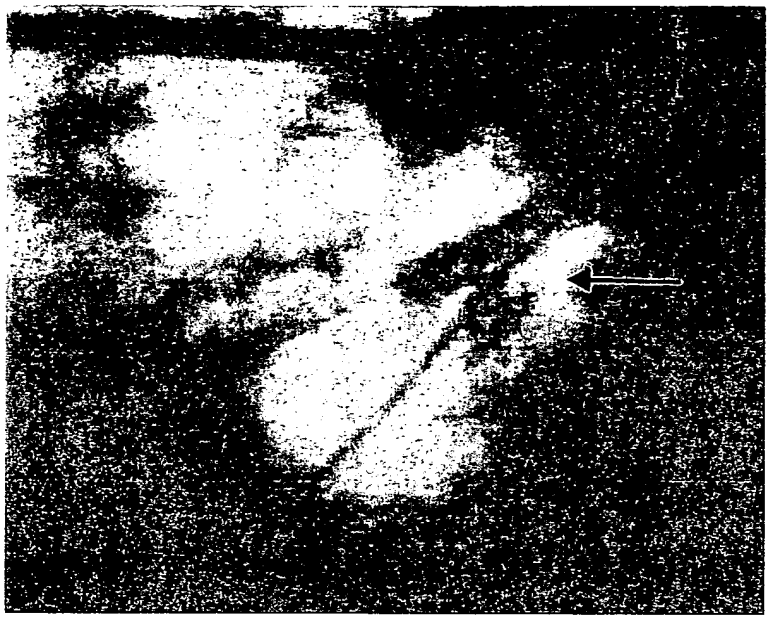


Figure 14.16: The two expanded stents show a gap (arrow) at the ostium of the diagonal.

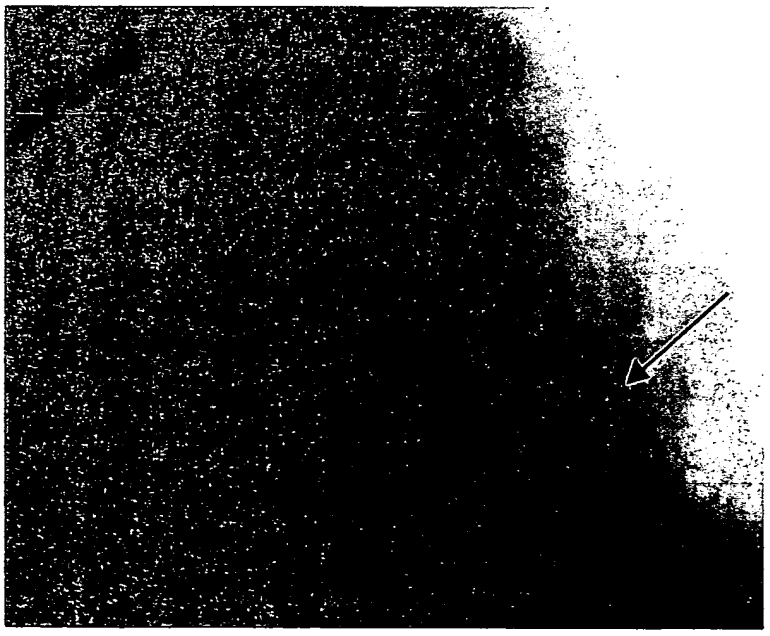


Figure 14.17: After deployment of a third stent (arrow) the bifurcation is fully covered.

Figure 14.18: Final result demonstrating that the NIROYAL does not hide angiographic details.

Case 2:

A tight lesion (99%) in the right Renal Artery (Figure 14.19) was treated with a NIR Peripheral stent 19 mm long (Figure 14.20). The easy insertion of this flexible peripheral stent allowed for a near ideal result (Figure 14.21).

Figure 14.19: A renal artery with 99% lesion and a sharp take-off from the aorta.

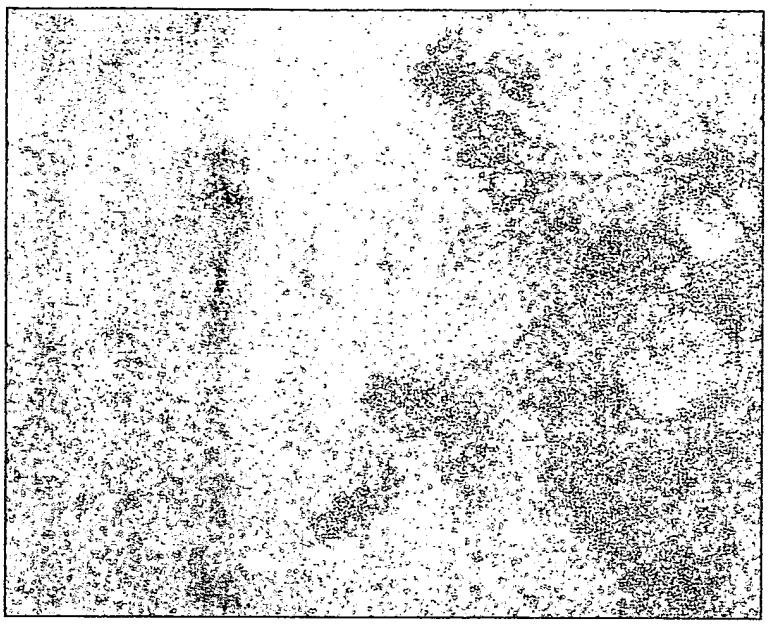


Figure 14.20: Insertion of the 9-19 NIR peripheral stent, note the flexing of the stent.

Figure 14.21: Final result with stent expanded to 8 mm.

19. THE JOSTENT® CORONARY STENT RANGE

JOMED International AB, Helsingborg, Sweden

Hakan Emanuelsson and Nick Byrne

Description	Balloon expandable stainless steel slotted tube stent, designed in order to allow optimal expansion while maximizing radial strength.

History

- Early 1995 animal trials
- First human implants of JOSTENT® M February 1996
- Corline™ Heparinized Surface introduced 1996
- JOSTENT® Side Branch launched February 1997
- JOSTENT® Bifurcation launched April 1997
- JOMED LOGO eX PTCA Catheter launched May 1997
- JOSTENT® Delivery System August 1997
- JOSTENT® FLEX + PLUS launched September 1997
- JOSTENT coronary stent graft launched September 1997

JOSTENT® Plus

General description

The new JOSTENT® Plus is based upon a multicellular geometry, and includes a stronger strut design for improved radial strength whilst incorporating an new 'loop design' to enhance flexibility. This new design provides increased individual cell area and further provides options to allow implantation in vessels of up to 6 mm (0.236 inch) diameter, whilst maintaining moderate foreshortening.

The JOSTENT® Plus is laser cut from a single piece of stainless steel tube and requires no weld points. The stent is then polished leaving a clean surface area with rounded struts, free of any unwanted particles. This guarantees an easy stent loading without damaging the balloon (Figure 19.1).

The new JOSTENT® Plus is mounted on a high-pressure balloon delivery system. It has a rated burst pressure of 12–16 atmospheres with an average burst of about 20 atmospheres and provides a crimped stent profile of about 1.0 mm (0.04 inch) (see Figure 19.2).

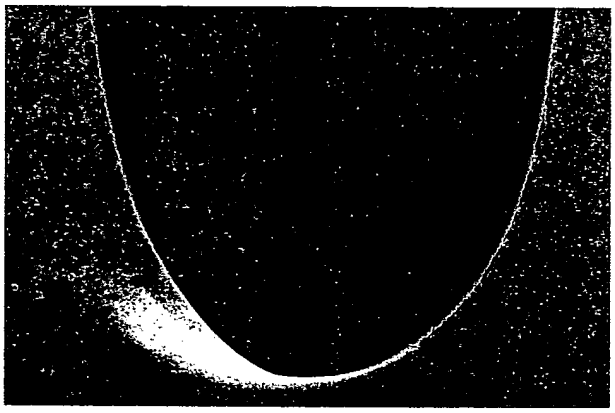


Figure 19.1: SEM photograph of strut surface

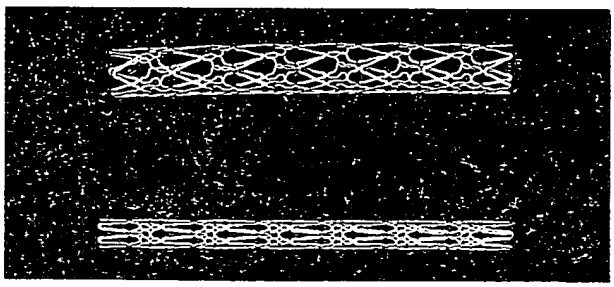


Figure 19.2: JOSTENT® Plus (expanded + unmounted)

JOSTENT® Plus technical specifications	
Material composition:	316L stainless steel
Degree of radio-opacity:	Moderate
Ferromagnetism:	None
Metallic surface area (in expandable state):	14–19%
Metallic recoil:	<3%
Strut design:	Rounded edges
Strut thickness:	0.09 mm (0.0035 inch)
Crimped profile:	≈1 mm (0.04 inch), balloon dependant
Longitudinal flexibility:	Very good
Percentage shortening on expansion:	<3% at 3.5 mm
Available lengths:	9, 17, 25, 33 mm
Available expanded diameters:	2.0–6.0 mm diameter
Other non-coronary types:	Carotid/Vascular/Billary

JOSTENT® Flex

General description

The new JOSTENT® Flex is specially designed for intricate vessels difficult to reach. The JOSTENT® Flex combines flexibility with high radial strength, making it one of the most flexible slotted tube stents available. This new design provides increased individual cell area and further provides options to allow implantation in vessels of up to 5 mm (0.20 inch) diameter.

The JOSTENT® Flex is laser cut from a single piece of stainless steel tube and requires no weld points. The stent is then polished leaving a clean surface area with rounded struts, free of any unwanted particles. This guarantees an easy stent loading without damaging the balloon (Figure 19.3).

The new JOSTENT® Flex is mounted on a high-pressure balloon delivery system. It has a rated burst pressure of 12–16 atmospheres with an average burst of about 20 atmospheres and provides a crimped stent profile of about 1.0 mm (0.04 inch) (see Figure 19.4).

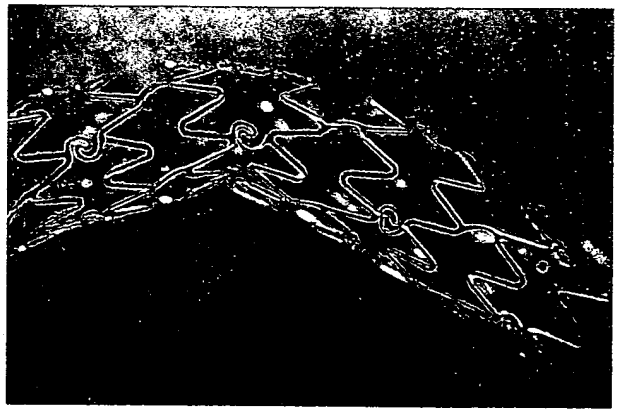


Figure 19.3: JOSTENT® Flex

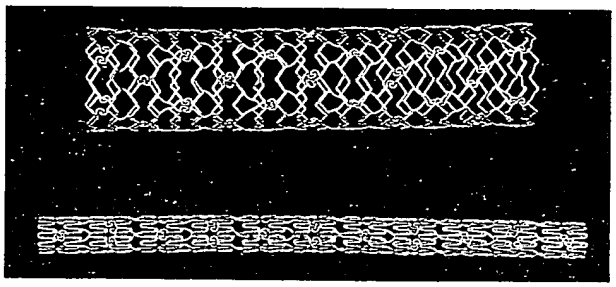


Figure 19.4: JOSTENT® Flex (expanded + unmounted)

JOSTENT® Flex technical specifications	
Material composition:	316L stainless steel
Degree of radio-opacity:	Moderate
Ferromagnetism:	None
Metallic surface area (in expandable state):	14–19%
Metallic recoil:	<3%
Strut design:	Rounded edges
Strut thickness:	0.09 mm (0.0035 inch)
Crimped profile:	~1 mm (0.04 inch), balloon dependant
Longitudinal flexibility:	Superior
Percentage shortening on expansion:	<3% at 3.5 mm
Available lengths:	9, 16, 26, 32 mm
Available expanded diameters:	2.0–5.0 mm diameter
Other non-coronary types:	Carotid/Vascular/Billary

JOSTENT® delivery system	
Mechanism of deployment:	Balloon expandable
Minimum I.D. of guide catheter:	0.064 inch (1.63 mm, 6 Fr)
Premounted on delivery catheter:	Yes
Protective sheath/cover:	No
Position of radio-opaque markers:	Distal, proximal and mid
Further balloon expansion:	At physicians discretion
Recrossability of implanted stents:	Excellent
Sizing:	To match vessel diameter

JOSTENT® Side Branch

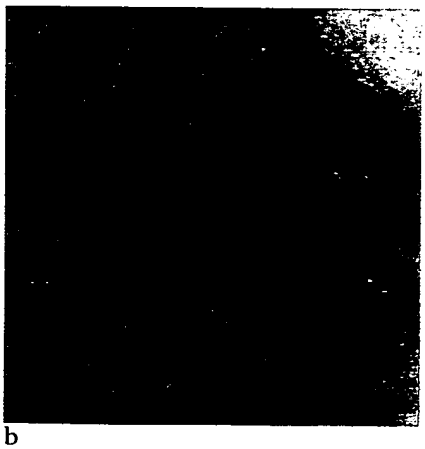
General description

The S design is the first stent produced specifically for the side branch application and incorporates cells that can be expanded to 3.5 mm diameter to allow access for further stenting of side branches (Figures 19.5(a)–(c)).

The JOSTENT® Side Branch has an 8 cell uniform construction with a reinforced 4 cell central section, therefore providing overall radial strength over the entire stent length (Figures 19.6(a) and (b)).

The JOSTENT® Side Branch is available as a bare stent and in the balloon mounted form.

a



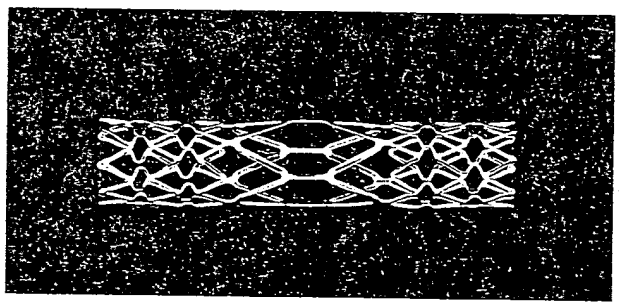
b

Figure 19.5: *(a) Angiogram of lesion at Side Branch.*

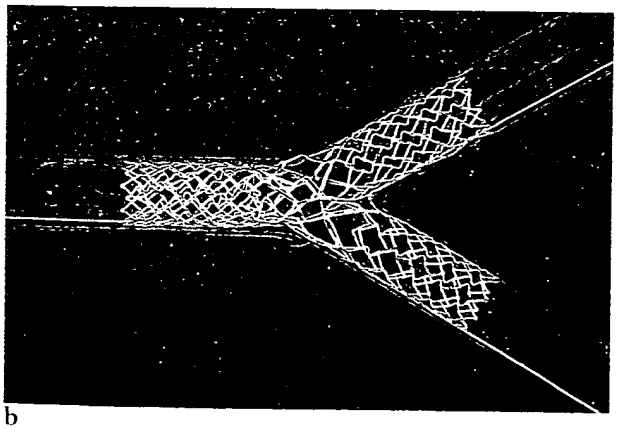
(b) Angiogram post placement of JOSTENT® Side Branch.

c

(c) IVUS of JOSTENT® Side Branch



a



b

Figure 19.6:
(a) JOSTENT® Side Branch.

(b) JOSTENT® Side Branch and bifurcation stent.

JOSTENT® Asymmetric Side Branch

General description

The JOSTENT® Asymmetric Side Branch is constructed similarly to the S Design. This stent has the row of larger cells positioned asymmetrically in order to allow stenting of lesions asymmetric to the side branch (Figure 19.7).

The JOSTENT® Asymmetric Side Branch is available as a bare stent and in a balloon mounted form.

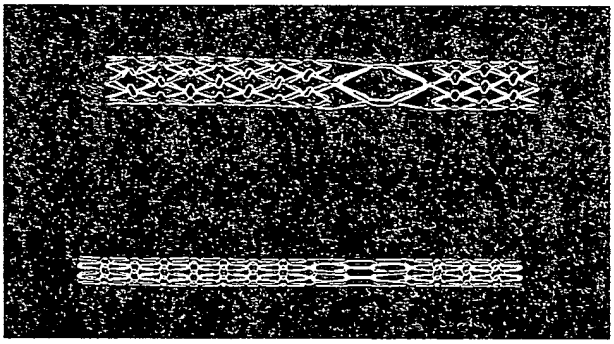


Figure 19.7: JOSTENT® Asymmetric Side Branch

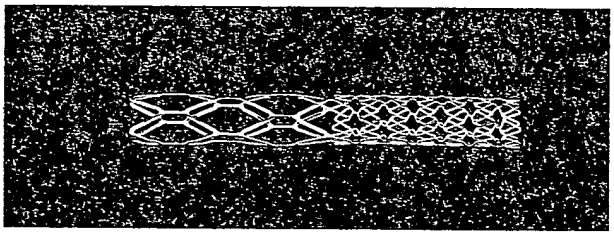
JOSTENT® Side Branch technical specification	
Material composition:	316L stainless steel
Degree of radio-opacity:	Moderate
Ferromagnetism:	None
Metallic area (expanded state):	10–16%
Metallic recoil:	<3%
Strut design:	Rounded edges
Strut thickness:	0.09 mm (0.0035 inch)
Crimped profile:	~1 mm (0.04 inch), balloon dependant
Longitudinal flexibility:	Good
Percentage shortening on expansion:	<3% at 3.5 mm
Available lengths:	17 and 28 mm
Available expanded diameters:	3.0–5.0 mm diameter
Other non-coronary types:	Iliac

JOSTENT® Bifurcation

General description

The JOSTENT® Bifurcation design has an 8 cell circumferential construction over half the stent length with either 2 or 3 rows of larger cells (depending on stent length) covering the remaining length. The larger cells can be post-dilated to 3.5 mm (0.14 inch) diameter to allow access for further placement in the bifurcated vessel (Figures 19.8(a) and (b)).

The larger vessel struts have been reinforced to provide continuous radial strength over the entire stent length. The JOSTENT® Bifurcation is available as a bare stent and in a balloon mounted form.



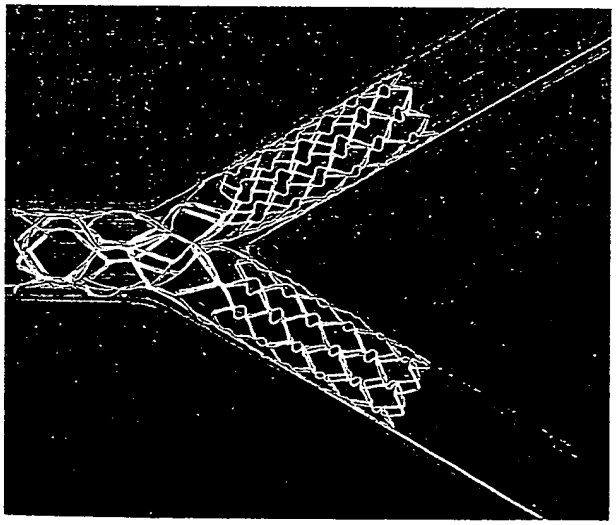


Figure 19.8: (a) JOSTENT® Bifurcation.

(b) JOSTENT® Bifurcation (2 stents placed in a bifurcation).

JOSTENT® Bifurcation technical specification	
Material composition:	316L stainless steel
Degree of radio-opacity:	Moderate
Ferromagnetism:	None
Metallic area (in expandable state):	10–16%
Metallic recoil:	<3%
Strut design:	Rounded edges
Strut thickness:	0.09 mm (0.0035 inch)
Crimped profile:	~1 mm (0.04 inch), balloon dependant
Longitudinal flexibility:	Good
Percentage shortening on expansion:	<3% at 3.5 mm
Available lengths:	19 and 26 mm
Available expanded diameters:	2.0–5.0 mm diameter
Other non-coronary types:	Iliac

JOSTENT® Coronary Stent Graft

General description

JOMED is developing a unique, new stent technology which may be the beginning of a new era in coronary stenting. Integrating the unique characteristics of a stent graft into a coronary stent through a patented sandwich technique, this device combines the best of two worlds. The PTFE graft material integrated in the stent effectively seals off a penetration, an aneurysm, thrombus or the entire lesion. The JOSTENT® Coronary Stent Graft has an extremely low crimped profile and is more flexible than most regular stents.

Initial animal trials have confirmed the non-thrombogenicity of the JOSTENT® Coronary Stent Graft.

Ongoing animal and clinical trials are designed to confirm the safety and efficacy of the device. A number of studies are currently planned to determine the long-term effect on restenosis (Figure 19.9).

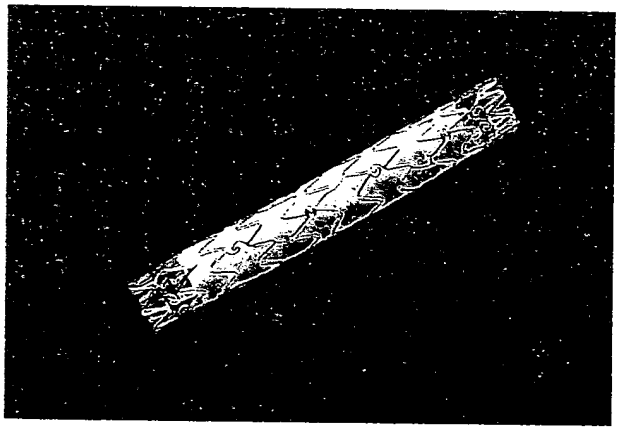


Figure 19.9: JOSTENT® coronary stent graft.

Corline™ Heparin Surface

All JoStents are available with the Corline™ Heparin surface treatment to render the stent non-thrombogenic for use in clinical studies and in countries where legal approval exists for routine use (Figures 19.10(a) and (b)).

The addition of a Heparin Surface has in earlier studies proven,[4] to still further reduce overall restenosis rates (13% versus 20% in earlier studies of untreated stents,[5] whilst reducing the sub-acute thrombosis rate to zero.

An ongoing trial (COAST) is testing the hypothesis that Heparin coated stents may be beneficial in small vessels (2.0–2.6 mm) and superior to regular stents and balloon angioplasty.

Figure 19.10:
(a) JoStent strut with Heparinized surface.

(b) Non-Heparinized.

Tips and tricks for delivery

For bare stents

1. Choose a semi-compliant or non-compliant balloon so that the same balloon can be used for post-stent dilatation.
2. Match the balloon to the length of the stent, e.g. a 16 mm stent on a 20 mm balloon.
3. Clean balloon of any silicon coating or blood.
4. Ensure that the balloon lumen is protected during stent crimping, by inserting a stylet or guidewire.
5. If the balloon has already been used for the PTA/PTCA procedure, refold the balloon using the manufacturers recommended device.
6. Position delivery tool over the refold balloon.

   Alternatively

   6a. Place the stent on the guidewire with the delivery device, and then advance the balloon through the stent for the crimping procedure.

7. Ensure that the stent is placed between or on the visible marker(s).
8. Crimp the stent uniformly until a low profile is achieved.
9. Make sure that the stent does not move on the balloon.
10. If this is the case inflate the balloon to 0.3–0.5 atmospheres to secure the crimped stent.

    Alternatively

    10a. Inflate the balloon up to 2 atmospheres, remove the dilated stent, inflate the balloon further up to high pressure, deflate the balloon and repeat the crimping procedure.

11. When inserting the stent, do not apply negative pressure to the balloon.

For balloon mounted and bare stents

12. Select 6–8 Fr guiding catheter based upon the operators preference.
13. Prepare the premounted catheter as usual. Apply negative pressure to the balloon lumen, and flush with guidewire lumen saline solution. When inserting the balloon, do not apply negative pressure.
14. Deliver the balloon and stent over an 0.014 inch guidewire.
15. Recommended stent deployment pressures 8–12 atmospheres.
16. Post dilate up to 18 atmospheres if required.

Indications for clinical use

All types of lesions including

- Ostial lesions
- Eccentric lesions
- Concentric lesions
- Long diffuse lesions
- Calcified lesions
- Side branch
- Bifurcation
- Vein grafts

in vessels from 2.0 to 6.0 mm diameter

Clinical trials

Trial name	COAST	KFHC Heparin Trial	SBS Registry	Heparin Stent Registry
No of patients	600	100 stents	100	200
Purpose	Compare the effects of Heparinized stents vs. uncoated stents and PTCA in small vessels (2.0–2.6 mm)	Evaluate the effects of Heparinized stents in small vessels	Data of Side Branch stent implantations	Evaluate the effects of Heparinized stents in regular vessels (3.0–5.0 mm)
Type of trial	Randomized	Registry	Registry	Registry
No. of centres	21	1	6	14
Commencement date	August 1997	May 1997	September 1997	October 1977
Geography	Europe	Middle East	Belgium	UK Germany

Review of the literature

Since the launch of the original JOSTENT® design in February 1996, there have been approx. 30,000 JOSTENT® implants worldwide indicating rapid user acceptance and approval.

The original JOSTENT® Open Registry Multicentre evaluation showed the JOSTENT® to be 'effective and safe in the acute situation',[1] resulting in a <10% restenosis rate at 6 month follow-up.[2]

Subsequent in-vitro data has confirmed the high radial strength of the JOSTENT® measured in MLD and recoil at 9 bar and 21 bar using X-ray with direct enlargement (DIMA) techniques.[3]

References

1. Multicentre Open Registry Evaluation of the JOSTENT® M.
2. University of Göttingen, data presented at German Heart Association meeting, Mannheim, December 1996.
3. University of Göttingen, data presented at German Heart Association meeting, Mannheim, December 1996.
4. Serruys PW, Emanuelsson H, van der Giessen W *et al*, on behalf of the Benestent II study group. Heparin coated Palmaz–Schatz stents in human coronary arteries. Early outcome of the Benestent 11 Pilot studies. *Circulation* 1996; **93**:412–422.
5. Serruys PW, de Jaegere P, Kiemeneij F *et al*, for the Benestent study group. A comparison of balloon angioplasty in patients with coronary artery diseases. *N Eng J Med* 1994; **331**:489–495.

The Publishers would like to thank JOMED for their support

JOMED

20. THE DIVYSIO STENT

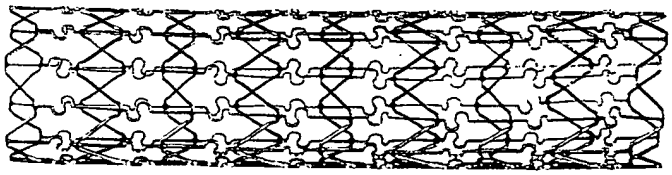
Biocompatibles Ltd, Surrey, UK

David C Cumberland

Description	Balloon expandable, laser cut from stainless steel tube, comprising interlocking arrowhead design.

History	• Developed by DivYsio Solutions Ltd in conjunction with Biocompatibles Ltd. The stent is provided with the phosphorylcholine containing polymer coating of Biocompatibles Ltd. • September 1996 first human coronary implant

a



b

Figure 20.1: 15 mm long 'closed' design. (a) as manufactured; (b) after expansion. In contrast with the 'open' design (Figure 20.4) there is a longitudinal strut in the space formed by the arrow heads.

The DivYsio stent technical specifications

Material composition:	316L stainless steel
Degree of radio-opacity (grade):	Moderate
Ferromagnetism:	None (MRI safe)
Metallic surface area expanded:	15 mm — 15% 28 mm — 12%
Metallic cross-sectional area:	15 mm and 28 mm stents Max: 0.008 mm^2; Min: 0.005 mm^2
Stent design:	Interlocking arrow heads
Strut design:	Rectangular, rounded edge
Strut dimension:	(15 mm Stent) Max: 0.083 mm (0.003 inch); Min: 0.050 mm (0.002 inch) (28 mm Stent) Max: 0.083 mm (0.003 inch); Min: 0.050 mm (0.002 inch)
Strut angles:	Complex
Strut thickness:	0.101 mm (0.004 inch)
Profile: non-expanded (uncrimped):	1.5 mm
Longitudinal flexibility:	15 mm medium, 28 mm high
Percentage shortening on expansion:	Less than 4% (1% at 3 mm)
Expansion range:	3.0 to 4.0 mm (not mounted)
Degree of recoil (shape memory):	1% at 4.0 mm
Radial force:	High (force to close > 1.5N)
Currently available diameters:	3.0 to 4.0 mm
Currently available lengths:	15 and 28 mm
Recrossability of implanted stent:	Good

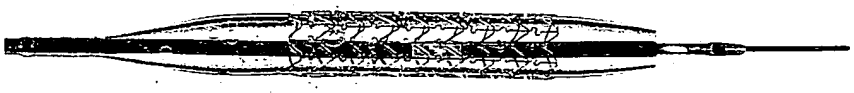


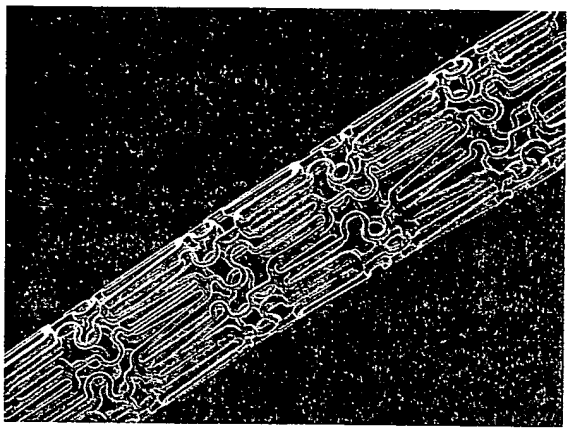
Figure 20.2: The 15 mm 'closed' design mounted on a 3.0 mm balloon (Bard Samba Rely) after deployment at 4 bar.

divYsio stent delivery	
Mechanism of deployment:	Balloon expandable
Mechanism of expanding:	Balloon expandable
Minimal internal diameter of guiding catheter:	6 Fr Compatible
Premounted on delivery catheter:	No
Premounted on a high pressure balloon:	No
Protective sheath/cover:	No
Offered as bare stent:	Yes
Position of radio-opaque markers:	None

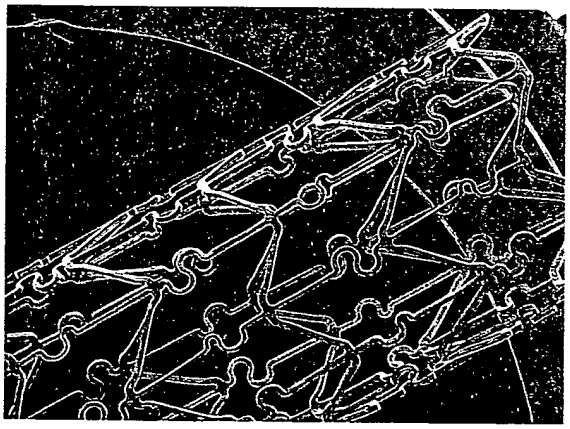
Tips and tricks for delivery

No particular tips for delivery, as the stent has been easily crimped and subsequently deployed on balloons from several manufacturers in the clinical experience so far. For example, the 28 mm stent has been frequently mounted on the 30 mm long Bard Samba Rely balloon. The stent is only moderately radio-opaque, in common with other stainless steel stents of this metal content.

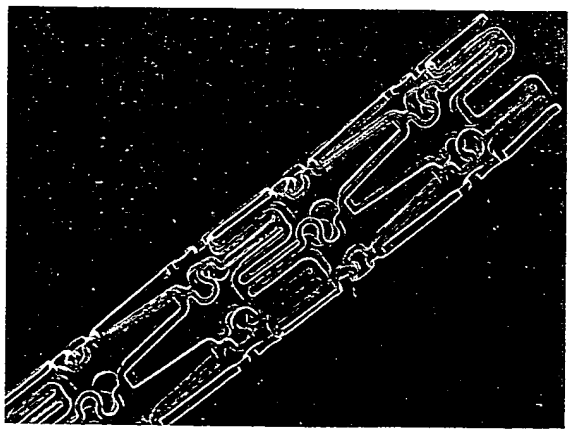
The stent is expanded fully at 4 bar pressure; thereafter the role of increasing pressure is dependent on the balloon.



a

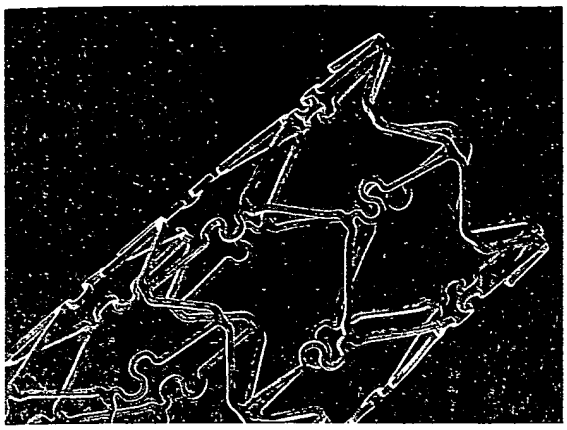


b



c

Figure 20.3: Electron micrographs of DivYsio stent. (a) 15 mm 'closed' design end section; (b) 15 mm expanded end section; (c) 28 mm 'open' design end section.



d

Figure 20.3:
(d) 28 mm 'open' design expanded end section.

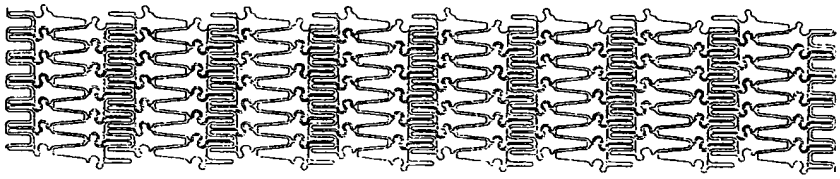
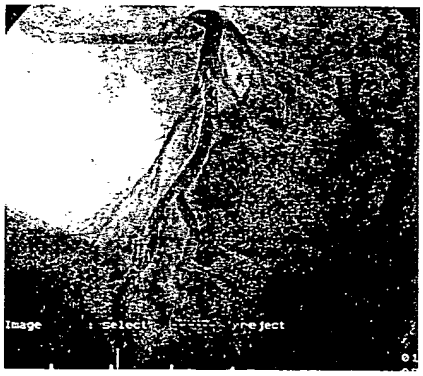


Figure 20.4: Drawing of 'open' design stent, with spaces enclosed by the arrow heads (in contrast to 'closed' design, Figure 20.1).

a



b

c

Figure 20.5: (a) Long mid-LAD stenosis in a patient with unstable angina; (b) after balloon angioplasty: inadequate lumen with dissection; (c) 24 hours after deployment of divYsio stent — smooth lumen, good conformity to vessel, side-branch patent.

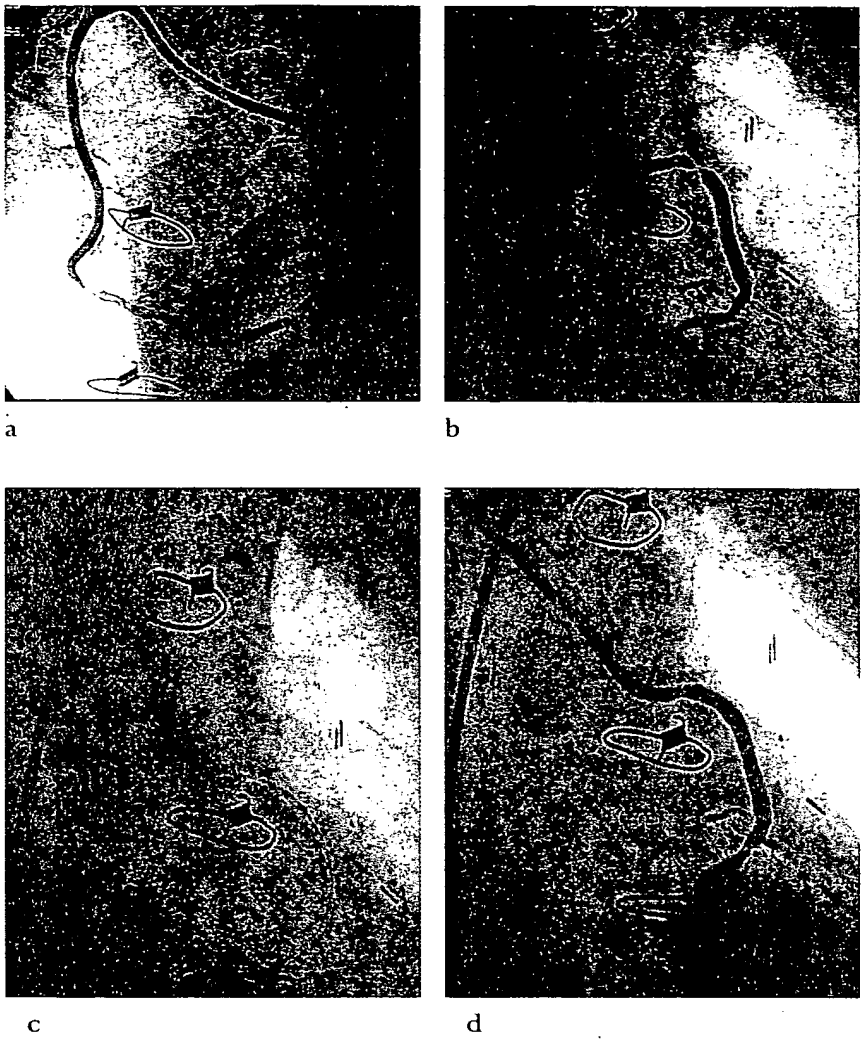
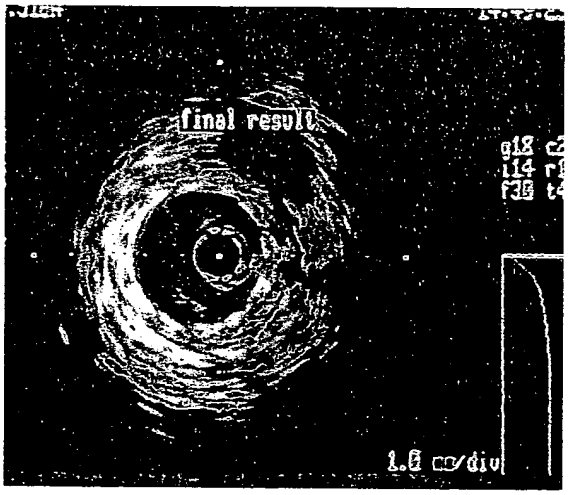


Figure 20.6: The first clinical divYsio stent implantation, performed by Antonio Colombo. The patient had had a right internal mammary artery attached to a saphenous vein, in turn previously grafted to an obtuse marginal artery. (a) The tortuous proximal path; (b) severe anastomotic stenosis; (c) 15 mm stent in place prior to deployment; (d) angiographic result after implantation.

a



b

Figure 20.7: IVUS images of lesion in Figure 20.6. (a) before; (b) after stenting. The even, circular appearance on IVUS is characteristic of this stent.

Indications for use

Indications are currently as for other coronary stents. Animal experiments suggest that PC coating may confer added clinical advantage in terms of reduced thrombogenicity. At the moment two types are available: a 15 mm 'closed' design which has a longitudinal member within the open space of each arrowhead (Figure 20.1) to confer greater support, and a 28 mm 'open version' without the longitudinal member (Figure 20.4), which has greater flexibility and potential for side-branch access (although the current clinical experience in respect of side-branch access and preservation with the 15 mm stent has been favorable). Both stents have six elements circumferentially, for use in vessels between 3.0 and 4.0 mm diameter. A 'family' of stents with variations on these themes for various clinical and technical indications, including a five element version for small vessels, is being developed.

Why I like the divYsio stent

- Ease and security of crimping on a variety of balloons.
- Good compromise between flexibility and vessel support.
- Ability for low pressure, symmetrical deployment.
- Cosmetically attractive appearances on angiography and intravascular ultrasound.
- Future family of stents based on fundamental design.
- Phosphorylcholine containing polymer coating, shown in animals to reduce thrombosis and possibly intimal hyperplasia; potential for local drug delivery.

Clinical trials

- CE Mark Study. n = 100 patients, 10 European centers. Single lesions suitable for 15 mm or 28 mm stent.
  End points: 1) Primary technical and clinical success.
  2) Freedom from major adverse cardiac events at 30 days and 6 months.
  Purpose of study: For European regulatory (CE mark) approval.
- SOPHOS Study. n = 150 patients, 15 European, 2 Canadian centers. Comprises single lesions similar to those in BENESTENT 1 trial, suitable for insertion of single 15 mm stent.
  End points: 1) Incidence of major cardiac events, subacute thrombosis at 30 days.
  2) 6 months angiographic, 9 months clinical status.
  Purpose of study: Comparison with experience of other stents.
- Global Stent Registry. World-wide registry of implantations using the developing family of divYsio stents for specific indications.

Acknowledgment

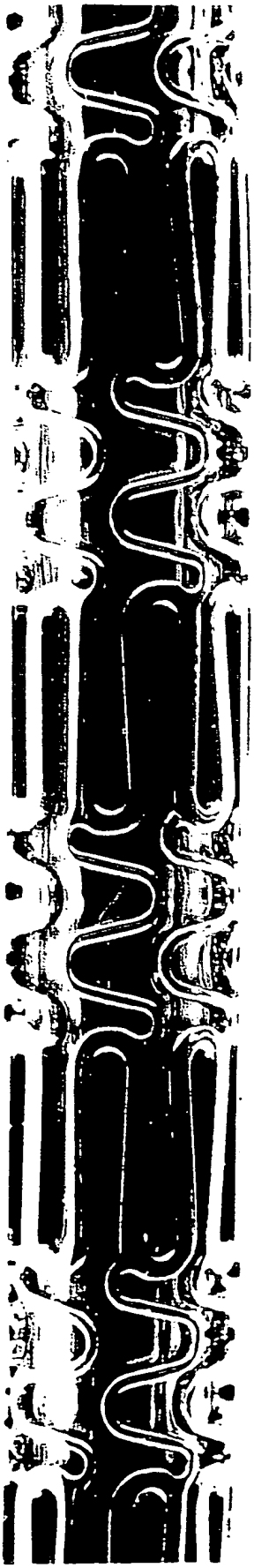
Figures 20.6 and 20.7 reproduced with kind permission of Dr Antonio Colombo.

References

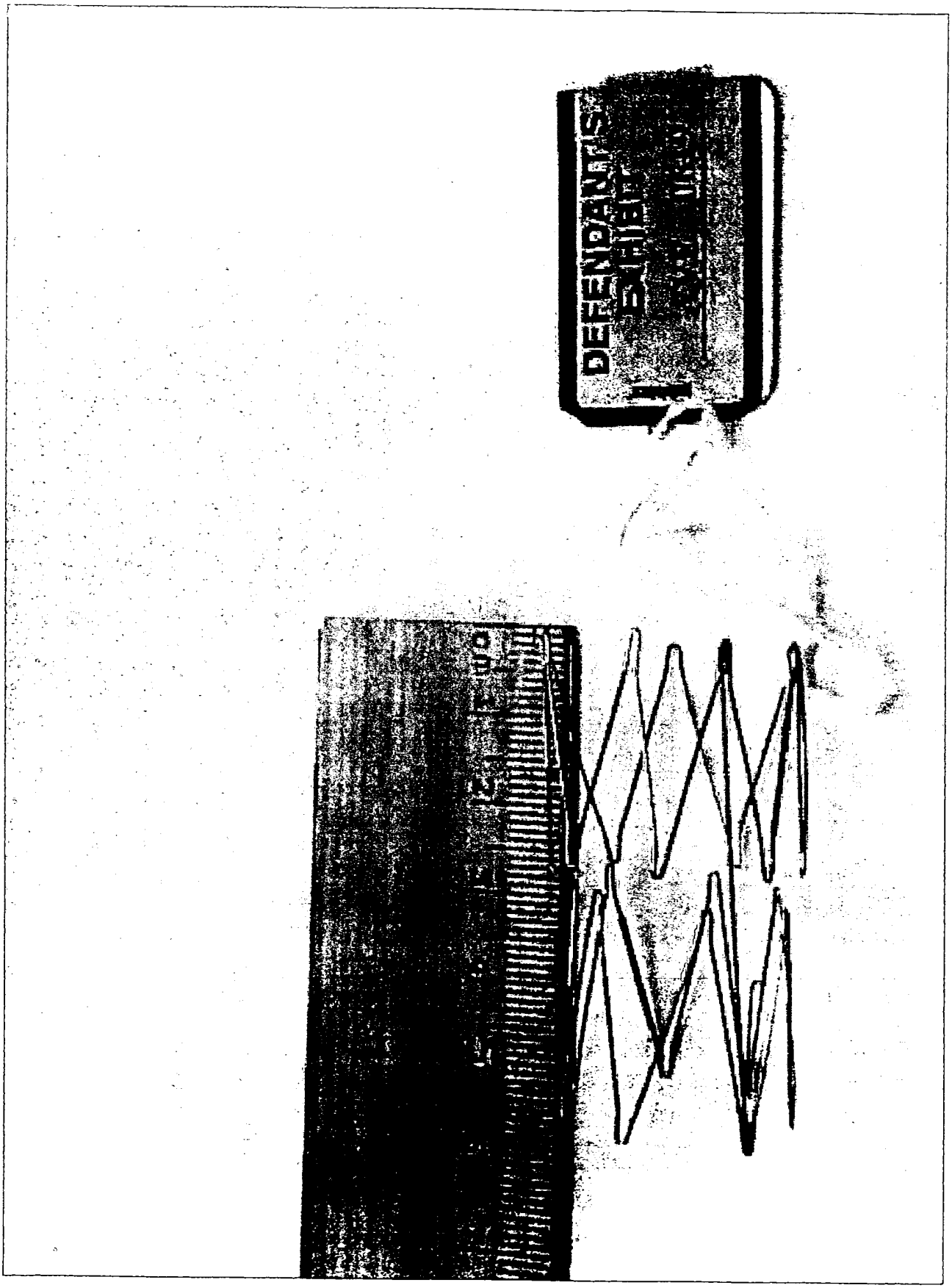
There have as yet been no publications on the divYsio stent. There are publications outside the angioplasty literature on the phosphorylcholine coating.

VonSegesser LK, Olah A, Leskosek B *et al.* Coagulation patterns in bovine left heart bypass with phospholipid versus heparin surface coating. *ASAIO Transactions* 1993;Jan–Mar.

Yianni YP. Biocompatible surfaces based upon biomembrane mimicry. In Quinn PJ, Cherry RJ (Eds), *Structural and Dynamic Properties of Lipids and Membranes.* Portland Press Research Monograph 1992;187–216.



Appln. No. 09/287,216
Exhibit B
to Reply of June 11, 2001



Appln. No. 09/287,216
Exhibit C
to Reply of June 11, 2001

cm
2

cm
1
2

MARKS' STANDARD HANDBOOK FOR MECHANICAL ENGINEERS

TENTH EDITION

EUGENE A. AVALLONE
THEODORE BAUMEISTER III

Marks'

Standard Handbook for Mechanical Engineers

Revised by a staff of specialists

EUGENE A. AVALLONE *Editor*

Consulting Engineer; Professor of Mechanical Engineering, Emeritus
The City College of the City University of New York

THEODORE BAUMEISTER III *Editor*

Retired Consultant, Information Systems Department
E. I. du Pont de Nemours & Co.

Tenth Edition

McGraw-Hill
New York San Francisco Washington, D.C. Auckland Bogotá
Caracas Lisbon London Madrid Mexico City Milan
Montreal New Delhi San Juan Singapore
Sydney Tokyo Toronto

Library of Congress Cataloged The First Issue
of this title as follows:

Standard handbook for mechanical engineers. 1st-ed.;
1916–

New York, McGraw-Hill.

v. Illus. 18–24 cm.

Title varies: 1916–58; Mechanical engineers' handbook.
Editors: 1916–51, L. S. Marks.—1958– T. Baumeister.
Includes bibliographies.

1. Mechanical engineering—Handbooks, manuals, etc. I. Marks, Lionel Simeon, 1871– ed. II. Baumeister, Theodore, 1897– ed. III. Title; Mechanical engineers' handbook.
TJ151.S82 502'.4'621 16–12915

Library of Congress Catalog Card Number: 87-641192

MARKS' STANDARD HANDBOOK FOR MECHANICAL ENGINEERS

McGraw-Hill

A Division of The McGraw-Hill Companies

67890 DOW/DOW 90109

ISBN 0-07-004997-1

The sponsoring editors for this book were Robert W. Hauserman and Robert Esposito, the editing supervisor was David E. Fogarty, and the production supervisor was Suzanne W. B. Rapcavage. It was set in Times Roman by Progressive Information Technologies.

Printed and bound by R. R. Donnelley & Sons Company.

This book is printed on acid-free paper.

The editors and the publishers will be grateful to readers who notify them of any inaccuracy or important omission in this book.

5.1 MECHANICAL PROPERTIES OF MATERIALS

by John Symonds, Expanded by Staff

REFERENCES: Davis et al., "Testing and Inspection of Engineering Materials," McGraw-Hill, Timoshenko, "Strength of Materials," pt. II, Van Nostrand. Richards, "Engineering Materials Science," Wadsworth. Nadai, "Plasticity," McGraw-Hill. Tetelman and McEvily, "Fracture of Structural Materials," Wiley. "Fracture Mechanics," ASTM STP-833. McClintock and Argon (eds.), "Mechanical Behavior of Materials," Addison-Wesley. Dieter, "Mechanical Metallurgy," McGraw-Hill. "Creep Data," ASME. ASTM Standards, ASTM. Blaznynski (ed.), "Plasticity and Modern Metal Forming Technology," Elsevier Science.

STRESS-STRAIN DIAGRAMS

The Stress-Strain Curve The engineering tensile stress-strain curve is obtained by **static loading** of a standard specimen, that is, by applying the load slowly enough that all parts of the specimen are in equilibrium at any instant. The curve is usually obtained by controlling the loading rate in the tensile machine. ASTM Standards require a loading rate not exceeding 100,000 lb/in² (70 kgf/mm²)/min. An alternate method of obtaining the curve is to specify the strain rate as the independent variable, in which case the loading rate is continuously adjusted to maintain the required strain rate. A strain rate of 0.05 in/in/(min) is commonly used. It is measured usually by an extensometer attached to the gage length of the specimen. Figure 5.1.1 shows several stress-strain curves.

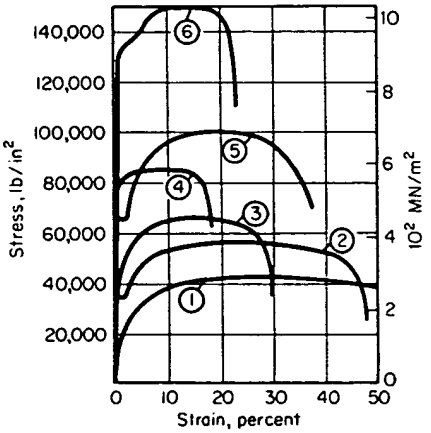


Fig. 5.1.1. Comparative stress-strain diagrams. (1) Soft brass; (2) low carbon steel; (3) hard bronze; (4) cold rolled steel; (5) medium carbon steel, annealed; (6) medium carbon steel, heat treated.

For most engineering materials, the curve will have an initial linear elastic region (Fig. 5.1.2) in which deformation is reversible and time-independent. The slope in this region is **Young's modulus** E. The **proportional elastic limit** (PEL) is the point where the curve starts to deviate from a straight line. The **elastic limit** (frequently indistinguishable from PEL) is the point on the curve beyond which plastic deformation is present after release of the load. If the stress is increased further, the stress-strain curve departs more and more from the straight line. Unloading the specimen at point X (Fig. 5.1.2), the portion XX' is linear and is essentially parallel to the original line OX''. The horizontal distance OX' is called the **permanent set** corresponding to the stress at X. This is the basis for the construction of the arbitrary **yield strength**. To determine the yield strength, a straight line XX' is drawn parallel to the initial elastic line OX'' but displaced from it by an arbitrary value of permanent strain. The permanent strain commonly used is 0.20 percent of the original gage length. The intersection of this line with the curve determines the stress value called the yield strength. In reporting the yield strength, the amount of permanent set should be specified. The arbitrary yield strength is used especially for those materials not exhibiting a natural yield point such as nonferrous metals; but it is not limited to these. Plastic behavior is somewhat time-dependent, particularly at high temperatures. Also at high temperatures, a small amount of time-dependent reversible strain may be detectable, indicative of **anelastic** behavior.

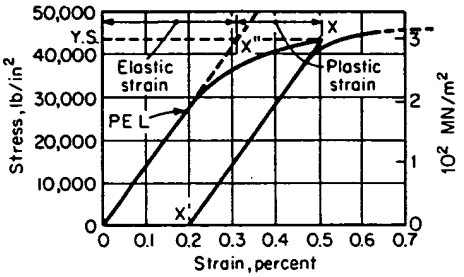


Fig. 5.1.2. General stress-strain diagram.

The **ultimate tensile strength** (UTS) is the maximum load sustained by the specimen divided by the original specimen cross-sectional area. The percent **elongation at failure** is the plastic extension of the specimen at failure expressed as (the change in original gage length × 100) divided by the original gage length. This extension is the sum of the **uniform** and **nonuniform** elongations. The uniform elongation is that which occurs prior to the UTS. It has an unequivocal significance, being associated with uniaxial stress, whereas the nonuniform elongation which occurs during localized extension (necking) is associated with triaxial stress. The nonuniform elongation will depend on geometry, particularly the ratio of specimen gage length L_0 to diameter D or square root of cross-sectional area A. ASTM Standards specify test-specimen geometry for a number of specimen sizes. The ratio $L_0/\sqrt{A}$ is maintained at 4.5 for flat- and round-cross-section specimens. The original gage length should always be stated in reporting elongation values.

The specimen percent **reduction in area** (RA) is the contraction in cross-sectional area at the fracture expressed as a percentage of the original area. It is obtained by measurement of the cross section of the broken specimen at the fracture location. The RA along with the load at fracture can be used to obtain the **fracture stress**, that is, fracture load divided by cross-sectional area at the fracture. See Table 5.1.1.

The type of fracture in tension gives some indications of the quality of the material, but this is considerably affected by the testing temperature, speed of testing, the shape and size of the test piece, and other conditions. Contraction is greatest in tough and ductile materials and least in brittle materials. In general, fractures are either of the **shear** or of the **separation** (loss of cohesion) type. Flat tensile specimens of ductile metals often show shear failures if the ratio of width to thickness is greater than 6:1. A completely shear-type failure may terminate in a chisel edge, for a flat specimen, or a point rupture, for a round specimen. Separation failures occur in brittle materials, such as certain cast irons. Combinations of both shear and separation failures are common on round specimens of ductile metal. Failure often starts at the axis in a necked region and produces a relatively flat area which grows until the material shears along a cone-shaped surface at the outside of the speci-

Table 5.1.1 Typical Mechanical Properties at Room Temperature
(Based on ordinary stress-strain values)

Metal	Tensile strength, 1,000 lb/in²	Yield strength, 1,000 lb/in²	Ultimate elongation, %	Reduction of area, %	Brinell no.
Cast iron	18–60	8–40	0	0	100–300
Wrought iron	45–55	25–35	35–25	55–30	100
Commercially pure iron, annealed	42	19	48	85	70
Hot-rolled	48	30	30	75	90
Cold-rolled	100	95			200
Structural steel, ordinary	50–65	30–40	40–30		120
Low-alloy, high-strength	65–90	40–80	30–15	70–40	150
Steel, SAE 1300, annealed	70	40	26	70	150
Quenched, drawn 1,300°F	100	80	24	65	200
Drawn 1,000°F	130	110	20	60	260
Drawn 700°F	200	180	14	45	400
Drawn 400°F	240	210	10	30	480
Steel, SAE 4340, annealed	80	45	25	70	170
Quenched, drawn 1,300°F	130	110	20	60	270
Drawn 1,000°F	190	170	14	50	395
Drawn 700°F	240	215	12	48	480
Drawn 400°F	290	260	10	44	580
Cold-rolled steel, SAE 1112	84	76	18	45	160
Stainless steel, 18-S	85–95	30–35	60–55	75–65	145–160
Steel castings, heat-treated	60–125	30–90	33–14	65–20	120–250
Aluminum, pure, rolled	13–24	5–21	35–5		23–44
Aluminum-copper alloys, cast	19–23	12–16	4–0		50–80
Wrought, heat-treated	30–60	10–50	33–15		50–120
Aluminum die castings	30		2		
Aluminum alloy 17ST	56	34	26	39	100
Aluminum alloy 51ST	48	40	20	35	105
Copper, annealed	32	5	58	73	45
Copper, hard-drawn	68	60	4	55	100
Brasses, various	40–120	8–80	60–3		50–170
Phosphor bronze	40–130		55–5		50–200
Tobin bronze, rolled	63	41	40	52	120
Magnesium alloys, various	21–45	11–30	17–0.5		47–78
Monel 400, Ni-Cu alloy	79	30	48	75	125
Molybdenum, rolled	100	75	30		250
Silver, cast, annealed	18	8	54		27
Titanium 6–4 alloy, annealed	130	120	10	25	352
Ductile iron, grade 80-55-06	80	55	6		225–255

NOTE: Compressive strength of cast iron, 80,000 to 150,000 lb/in².
Compressive yield strength of all metals, except those cold-worked = tensile yield strength.
Stress 1,000 lb/in² × 6.894 = stress, MN/m².

men, resulting in what is known as the cup-and-cone fracture. Double cup-and-cone and rosette fractures sometimes occur. Several types of tensile fractures are shown in Fig. 5.1.3.

Annealed or hot-rolled mild steels generally exhibit a **yield point** (see Fig. 5.1.4). Here, in a constant strain-rate test, a large increment of extension occurs under constant load at the elastic limit or at a stress just below the elastic limit. In the latter event the stress drops suddenly from the **upper yield point** to the **lower yield point.** Subsequent to the drop, the yield-point extension occurs at constant stress, followed by a rise to the UTS. Plastic flow during the yield-point extension is discontinuous;

Fig. 5.1.3. Typical metal fractures in tension.

successive zones of plastic deformation, known as **Luder's bands** or **stretcher strains**, appear until the entire specimen gage length has been uniformly deformed at the end of the yield-point extension. This behavior causes a banded or stepped appearance on the metal surface. The exact form of the stress-strain curve for this class of material is sensitive to test temperature, test strain rate, and the characteristics of the tensile machine employed.

The plastic behavior in a uniaxial tensile test can be represented as the **true stress-strain curve.** The **true stress** σ is based on the instantaneous

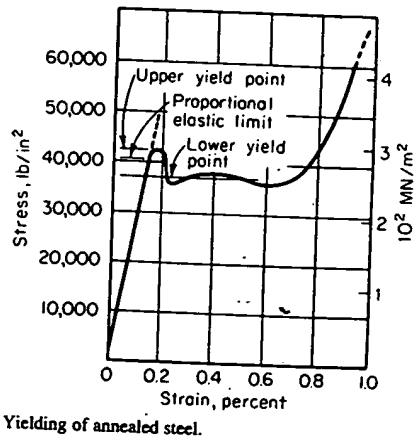


Fig. 5.1.4. Yielding of annealed steel.

cross section A, so that σ = load/A. The instantaneous true strain increment is $-dA/A$, or dL/L prior to necking. Total true strain ε is

$$\int_{A_0}^{A} -\frac{dA}{A} = \ln\left(\frac{A_0}{A}\right)$$

or $\ln (L/L_0)$ prior to necking. The true stress-strain curve or flow curve obtained has the typical form shown in Fig. 5.1.5. In the part of the test subsequent to the maximum load point (UTS), when necking occurs, the true strain of interest is that which occurs in an infinitesimal length at the region of minimum cross section. True strain for this element can still be expressed as $\ln (A_0/A)$, where A refers to the minimum cross section. Methods of constructing the true stress-strain curve are described in the technical literature. In the range between initial yielding and the neighborhood of the maximum load point the relationship between plastic strain ε_p and true stress often approximates

$$\sigma = k\varepsilon_p^n$$

where k is the **strength coefficient** and n is the **work-hardening exponent**. For a material which shows a yield point the relationship applies only to the rising part of the curve beyond the lower yield. It can be shown that at the maximum load point the slope of the true stress-strain curve equals the true stress, from which it can be deduced that for a material obeying the above exponential relationship between ε_p and n, $\varepsilon_p = n$ at the maximum load point. The exponent strongly influences the spread between YS and UTS on the engineering stress-strain curve. Values of n and k for some materials are shown in Table 5.1.2. A point on the flow curve indentifies the **flow stress** corresponding to a certain strain, that is, the stress required to bring about this amount of plastic deformation. The concept of true strain is useful for accurately describing large amounts of plastic deformation. The linear strain definition $(L - L_0)/L_0$ fails to correct for the continuously changing gage length, which leads to an increasing error as deformation proceeds.

During extension of a specimen under tension, the change in the specimen cross-sectional area is related to the elongation by **Poisson's ratio** μ, which is the ratio of strain in a transverse direction to that in the longitudinal direction. Values of μ for the elastic region are shown in Table 5.1.3. For plastic strain it is approximately 0.5.

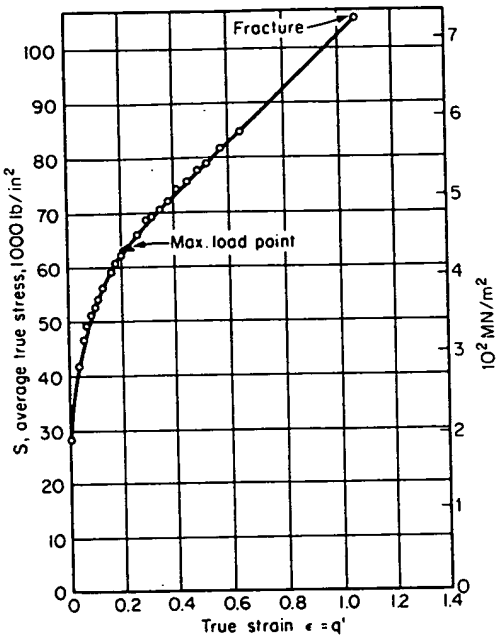


Fig. 5.1.5. True stress-strain curve for 20°C annealed mild steel.

Table 5.1.2 Room-Temperature Plastic-Flow Constants for a Number of Metals

Material	Condition	k, 1,000 in² (MN/m²)	n
0.40% C steel	Quenched and tempered at 400°F (478K)	416 (2,860)	0.08
0.05% C steel	Annealed and temper-rolled	72 (49.6)	0.23
2024 aluminum	Precipitation-hardened	100 (689)	0.16
2024 aluminum	Annealed	49 (338)	0.21
Copper	Annealed	46.4 (319)	0.54
70–30 brass	Annealed	130 (895)	0.49

SOURCE: Reproduced by permission from "Properties of Metals in Materials Engineering," ASM, 1949.

Table 5.1.3 Elastic Constants of Metals
(Mostly from tests of R. W. Vose)

Metal	E Modulus of elasticity (Young's modulus). 1,000,000 lb/in²	G Modulus of rigidity (shearing modulus). 1,000,000 lb/in²	K Bulk modulus. 1,000,000 lb/in²	μ Poisson's ratio
Cast steel	28.5	11.3	20.2	0.265
Cold-rolled steel	29.5	11.5	23.1	0.287
Stainless steel 18–8	27.6	10.6	23.6	0.305
All other steels, including high-carbon, heat-treated	28.6–30.0	11.0–11.9	22.6–24.0	0.283–0.292
Cast iron	13.5–21.0	5.2–8.2	8.4–15.5	0.211–0.299
Malleable iron	23.6	9.3	17.2	0.271
Copper	15.6	5.8	17.9	0.355
Brass, 70–30	15.9	6.0	15.7	0.331
Cast brass	14.5	5.3	16.8	0.357
Tobin bronze	13.8	5.1	16.3	0.359
Phosphor bronze	15.9	5.9	17.8	0.350
Aluminum alloys, various	9.9–10.3	3.7–3.9	9.9–10.2	0.330–0.334
Monel metal	25.0	9.5	22.5	0.315
Inconel	31	11		0.27–0.38
Z-nickel	30	11		±0.36
Beryllium copper	17	7		±0.21
Elektron (magnesium alloy)	6.3	2.5	4.8	0.281
Titanium (99.0 Ti), annealed bar	15–16	6.5		0.34
Zirconium, crystal bar	11–14			
Molybdenum, arc-cast	48–52			

the concentrated stress is larger than the ultimate strength of the material. In ductile materials, concentrated stresses higher than the yield strength will generally cause local plastic deformation and redistribution of stresses (rendering them more uniform). On the other hand, even with ductile materials areas of stress concentration are possible sites for fatigue if the component is cyclically loaded.

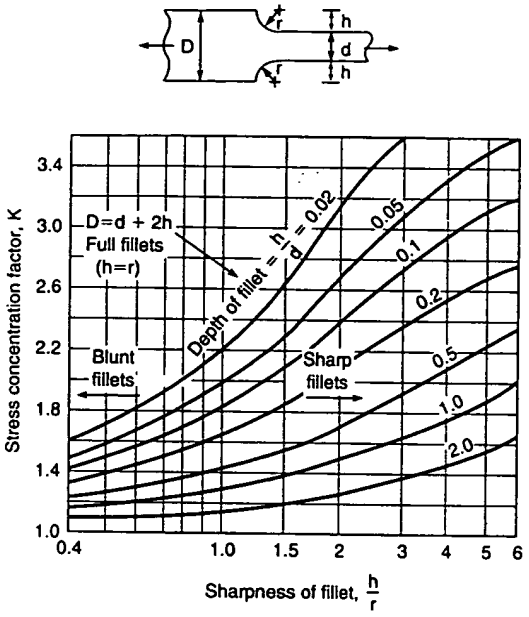


Fig. 5.1.8. Flat plate with fillets, in tension.

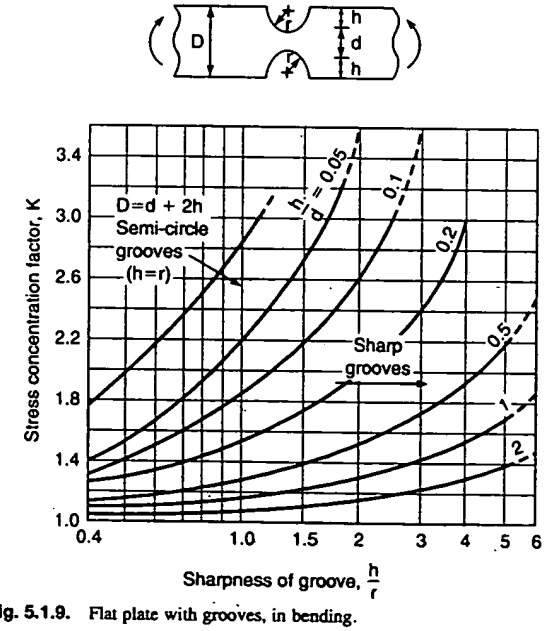


Fig. 5.1.9. Flat plate with grooves, in bending.

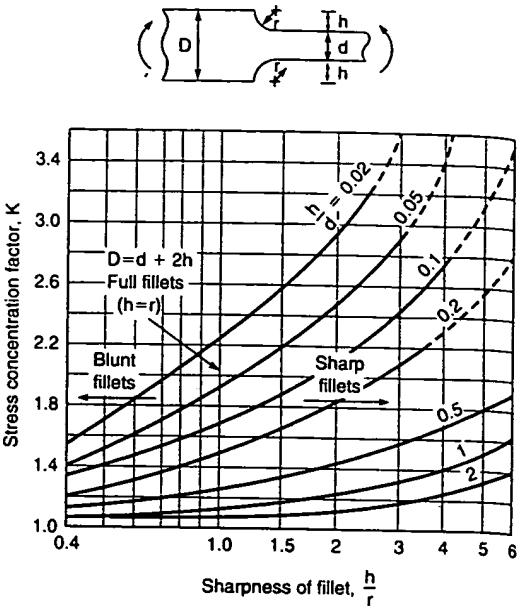


Fig. 5.1.10. Flat plate with fillets, in bending.

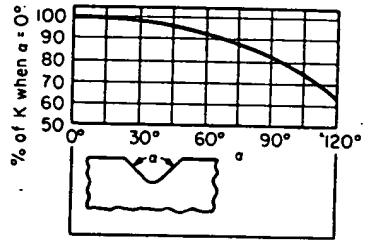


Fig. 5.1.11. Flat plate with angular notch, in tension or bending.

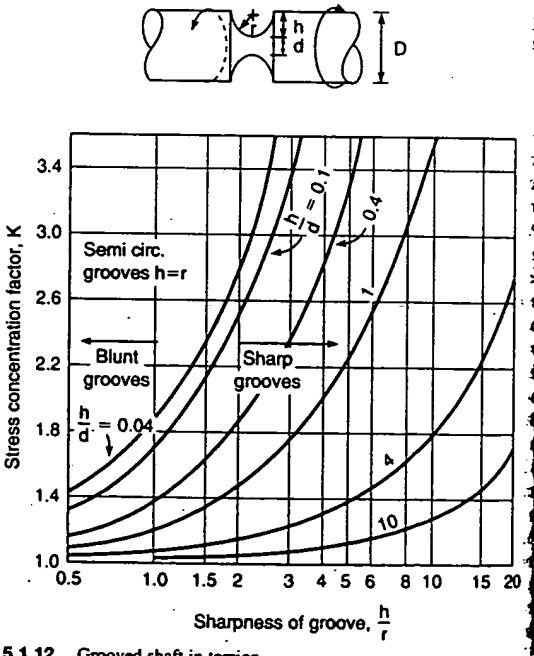


Fig. 5.1.12. Grooved shaft in torsion.

The general effect of increased strain rate is to increase the resistance to plastic deformation and thus to raise the flow curve. Decreasing test temperature also raises the flow curve. The effect of strain rate is expressed as **strain-rate sensitivity** m. Its value can be measured in the tension test if the strain rate is suddenly increased by a small increment during the plastic extension. The flow stress will then jump to a higher value. The strain-rate sensitivity is the ratio of incremental changes of $\log \sigma$ and $\log \dot{\epsilon}$

$$m = \left(\frac{\delta \log \sigma}{\delta \log \dot{\epsilon}}\right)_{\epsilon}$$

For most engineering materials at room temperature the strain rate sensitivity is of the order of 0.01. The effect becomes more significant at elevated temperatures, with values ranging to 0.2 and sometimes higher.

Compression Testing The compressive stress-strain curve is similar to the tensile stress-strain curve up to the yield strength. Thereafter, the progressively increasing specimen cross section causes the compressive stress-strain curve to diverge from the tensile curve. Some ductile metals will not fail in the compression test. Complex behavior occurs when the direction of stressing is changed, because of the **Bauschinger effect**, which can be described as follows: If a specimen is first plastically strained in tension, its yield stress in compression is reduced and vice versa.

Combined Stresses This refers to the situation in which stresses are present on each of the faces of a cubic element of the material. For a given cube orientation the applied stresses may include shear stresses over the cube faces as well as stresses normal to them. By a suitable rotation of axes the problem can be simplified: applied stresses on the new cubic element are equivalent to three mutually orthogonal **principal stresses** σ_1, σ_2, σ_3 alone, each acting normal to a cube face. Combined stress behavior in the elastic range is described in Sec. 5.2, Mechanics of Materials.

Prediction of the conditions under which plastic yielding will occur under combined stresses can be made with the help of several empirical theories. In the **maximum-shear-stress theory** the criterion for yielding is that yielding will occur when

$$\sigma_1 - \sigma_3 = \sigma_{ys}$$

in which σ_1 and σ_3 are the largest and smallest principal stresses, respectively, and σ_{ys} is the uniaxial tensile yield strength. This is the simplest theory for predicting yielding under combined stresses. A more accurate prediction can be made by the **distortion-energy theory**, according to which the criterion is

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_2 - \sigma_1)^2 = 2(\sigma_{ys})^2$$

Stress-strain curves in the plastic region for combined stress loading can be constructed. However, a particular stress state does not determine a unique strain value. The latter will depend on the stress-state path which is followed.

Plane strain is a condition where strain is confined to two dimensions. There is generally stress in the third direction, but because of mechanical constraints, strain in this dimension is prevented. Plane strain occurs in certain metalworking operations. It can also occur in the neighborhood of a crack tip in a tensile loaded member if the member is sufficiently thick. The material at the crack tip is then in triaxial tension, which condition promotes brittle fracture. On the other hand, ductility is enhanced and fracture is suppressed by triaxial compression.

Stress Concentration In a structure or machine part having a notch or any abrupt change in cross section, the maximum stress will occur at this location and will be greater than the stress calculated by elementary formulas based upon simplified assumptions as to the stress distribution. The ratio of this maximum stress to the nominal stress (calculated by the elementary formulas) is the stress-concentration factor K_t. This is a constant for the particular geometry and is independent of the material, provided it is isotropic. The stress-concentration factor may be determined experimentally or, in some cases, theoretically from the mathematical theory of elasticity. The factors shown in Figs. 5.1.6 to 5.1.13 were determined from both photoelastic tests and the theory of elasticity. Stress concentration will cause failure of brittle materials if

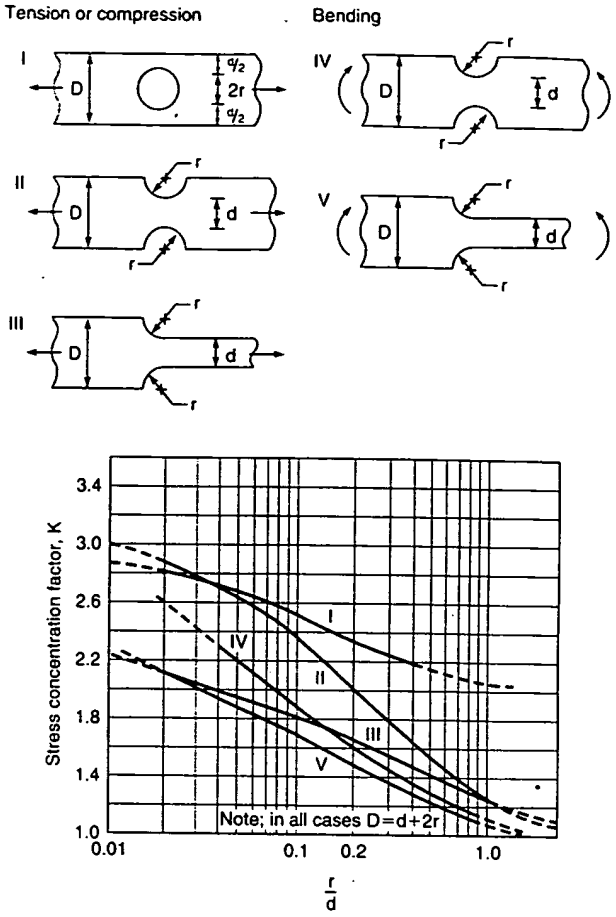


Fig. 5.1.6. Flat plate with semicircular fillets and grooves or with holes. I, II, and III are in tension or compression; IV and V are in bending.

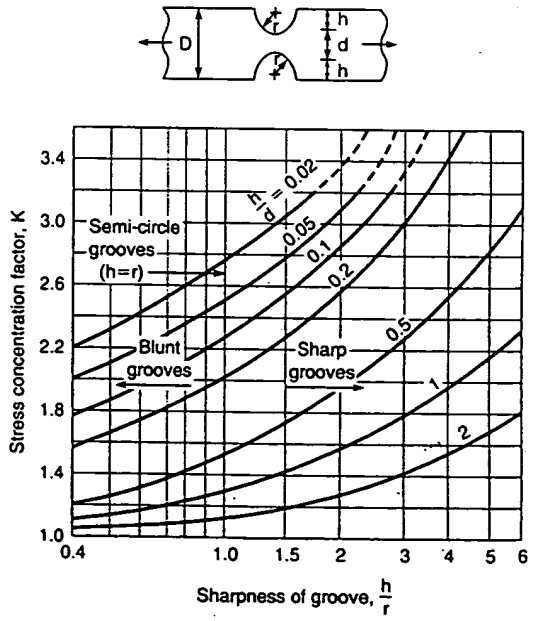


Fig. 5.1.7. Flat plate with grooves, in tension.

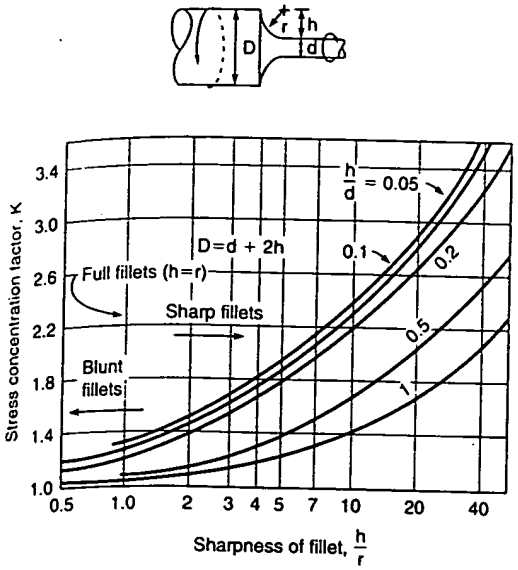


Fig. 5.1.13. Filleted shaft in torsion.

FRACTURE AT LOW STRESSES

Materials under tension sometimes fail by rapid fracture at stresses much below their strength level as determined in tests on carefully prepared specimens. These **brittle, unstable, or catastrophic failures** originate at preexisting stress-concentrating flaws which may be inherent in a material.

The **transition-temperature approach** is often used to ensure fracture-safe design in structural-grade steels. These materials exhibit a characteristic temperature, known as the **ductile brittle transition** (DBT) temperature, below which they are susceptible to brittle fracture. The transition-temperature approach to fracture-safe design ensures that the transition temperature of a material selected for a particular application is suitably matched to its intended use temperature. The DBT can be detected by plotting certain measurements from tensile or impact tests against temperature. Usually the transition to brittle behavior is complex, being neither fully ductile nor fully brittle. The range may extend over 200°F (110 K) interval. The **nil-ductility temperature** (NDT), determined by the **drop weight test** (see ASTM Standards), is an important reference point in the transition range. When NDT for a particular steel is known, temperature-stress combinations can be specified which define the limiting conditions under which catastrophic fracture can occur.

In the **Charpy V-notch** (CVN) impact test, a notched-bar specimen (Fig. 5.1.26) is used which is loaded in bending (see ASTM Standards). The energy absorbed from a swinging pendulum in fracturing the specimen is measured. The pendulum strikes the specimen at 16 to 19 ft (4.88 to 5.80 m)/s so that the specimen deformation associated with fracture occurs at a rapid strain rate. This ensures a conservative measure of toughness, since in some materials, toughness is reduced by high strain rates. A CVN impact energy vs. temperature curve is shown in Fig. 5.1.14, which also shows the transitions as given by percent brittle fracture and by percent lateral expansion. The CVN energy has no analytical significance. The test is useful mainly as a guide to the fracture behavior of a material for which an empirical correlation has been established between impact energy and some rigorous fracture criterion. For a particular grade of steel the CVN curve can be correlated with NDT. (See ASME Boiler and Pressure Vessel Code.)

Fracture Mechanics This analytical method is used for ultra-high-strength alloys, transition-temperature materials below the DBT temperature, and some low-strength materials in heavy section thickness.

Fracture mechanics theory deals with crack extension where plastic effects are negligible or confined to a small region around the crack tip. The present discussion is concerned with a through-thickness crack in a tension-loaded plate (Fig. 5.1.15) which is large enough so that the crack-tip stress field is not affected by the plate edges. Fracture mechanics theory states that unstable crack extension occurs when the work required for an increment of crack extension, namely, surface energy and energy consumed in local plastic deformation, is exceeded by the elastic-strain energy released at the crack tip. The elastic-stress

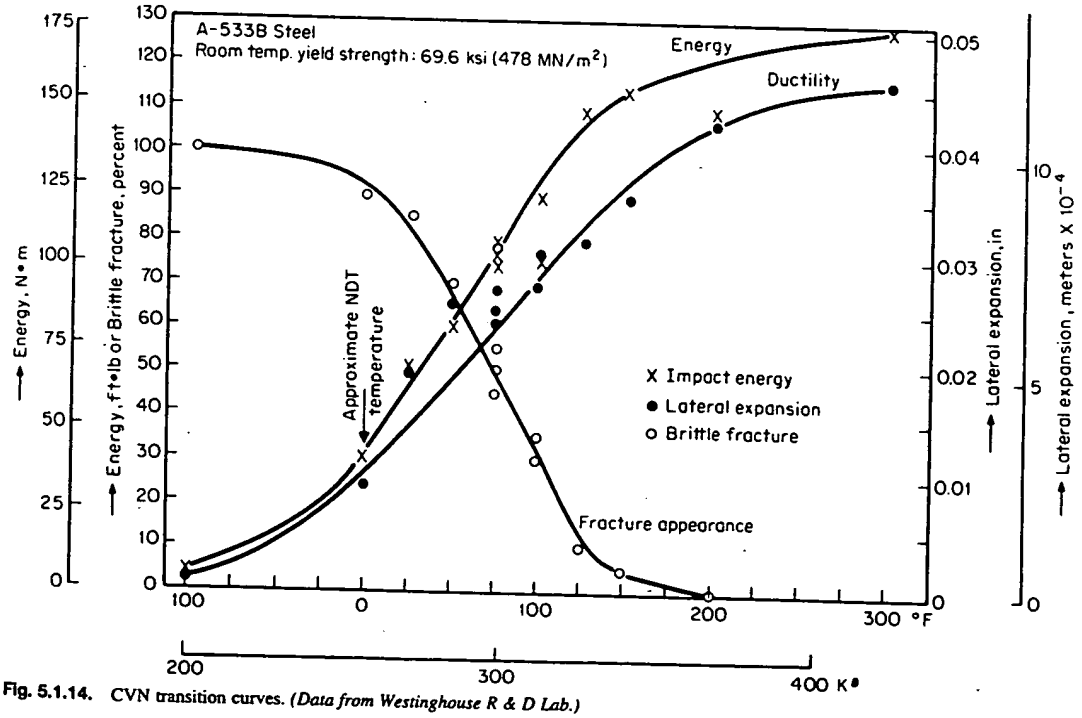


Fig. 5.1.14. CVN transition curves. *(Data from Westinghouse R & D Lab.)*

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 177 330 B1**

(12) # EUROPEAN PATENT SPECIFICATION

(45) Date of publication of patent specification: **19.06.91** (51) Int. Cl.5: **A61M 29/00**

(21) Application number: **85307008.4**

(22) Date of filing: **01.10.85**

(54) **Percutaneous endovascular stent.**

(30) Priority: **01.10.84 US 656261**

(43) Date of publication of application:
09.04.86 Bulletin 86/15

(45) Publication of the grant of the patent:
19.06.91 Bulletin 91/25

(84) Designated Contracting States:
AT BE CH DE FR GB IT LI LU NL SE

(56) References cited:
DE-C- 150 127
FR-A- 1 602 513
FR-A- 2 464 429
US-A- 1 672 591
US-A- 3 868 956
US-A- 4 214 587
US-A- 4 425 908

(73) Proprietor: **Cook Incorporated**
925 South Curry Pike P.O. Box 489
Bloomington Indiana 47402(US)

(72) Inventor: **Gianturco, Cesare**
2208 Valley Brook Drive, Champaign
Illinois 61821(US)

(74) Representative: **Bannerman, David Gardner et al**
Withers & Rogers 4 Dyer's Buildings Holborn
London, EC1N 2JT(GB)

EP 0 177 330 B1

Description

This invention relates to stents. It is desirable in various situations that means be provided for expanding a constricted vessel portion or for maintaining an open passageway through a vessel portion. Such situations arise, for example, in conjunction with the disease known as arteriosclerosis as well as the growth of a tumor so as to restrict or stop flow of blood through a blood vessel. Dr. Charles Dotter et al. reported in 1969 on the experimental use of coiled stainless steel wire stents placed in the popliteal arteries of dogs. Although the coils exhibited long-term patency, narrowing of the lumen occurred within them and only small coils could be passed percutaneously. See Dotter CT et al., Transluminally-Placed Coilspring Endoarterial Tube Grafts, Invest. Radiol., 1969; 4:329-332[1]. Recently, two laboratories reported on the use of a prosthesis constructed of a thermal shape memory alloy, nitinol, which is passed through a catheter. See Dotter CT et al., Transluminal Expandable Nitinol Coil Stent Grafting, Radiology, April, 1983; 147:259-260[2], and Cragg A. et al., Nonsurgical Placement of Arterial Endoprostheses, Radiology, April, 1983; 147:261-263[3]. Such stents can be complicated to use, requiring ice water or heated saline for placement. Also they have been found to produce luminal narrowing due to fibrin deposition on the stent wires.

Other references which may have relevance to the present invention are the following U.S. patents: Sakura 4,214,587; Alfidi 3,868,956; and Simon 4,425,908; and the Russian patent 978,821; also the following publications: C. Gianturco et al., A new vena cava filter: experimental animal evaluation, Radiology, December, 1980; 137: 835-837[4]; and M. Simon et al., A Vena Cava Filter Using Thermal Shape Memory Alloy, Diagnostic Radiology, 125:89-94, October 1977[5]. Still another reference publication is D. Maass et al., Radiology Follow-up of Transluminally Inserted Vascular Endoprostheses: An Experimental Study Using Expanding Sprials, Radiology, September, 1984; 152: 659-663.

US-A-1672591 relates to a resilient nostril dilator formed from a single length of wire bent into a configuration consisting of a number of bends joined by straight sections.

DE-C-150127 describes a dilator for the uterus consisting of a plurality of rods hinged together in a closed zig-zag configuration and expandible by an external actuating means.

Objects of the invention are to provide a stent which is easy to place and use and that reduces flow defects, luminal narrowing and occlusion.

This invention provides a stent comprising a single length of wire formed into a closed zig-zag configuration consisting of an endless series of straight sections joined by a plurality of bends, wherein the stent is resiliently depressible into a smaller first shape in which all of the straight sections are arranged side-by-side and closely adjacent one another for insertion into a passageway with the bends having a stress therein, and wherein the stent is resiliently expandable by release of said stress into a second shape in which all of the straight sections define a generally circular or cylindrical configuration for pressing against the wall of the passageway to maintain it open.

We also provide a combination of such a stent and a tubular cartridge having said stent therein, said stent being resiliently depressed into said smaller first shape.

This combination may additionally comprise a sheath having a lumen therethrough, said sheath having an adapter recess arranged coaxially with said lumen and enlarged in size relative to said lumen, and flexible member having a closed end and having an outer size sufficiently small to fit within said sheath yet sufficiently large to push said stent out of said sheath.

The wire is preferably of stainless steel with an O.D. of 0.046 cm (0.018 inches). In its second shape the stent is preferably either 5.5cm long and 4 cm in diameter, or 3.0 cm long and 2.5 cm in diameter.

The bends are preferably relatively sharp and are at a radius of preferably no more than 0.2 cm.

Stents embodying the invention and uses to which they may be put will now be described by way of example and with reference to the accompanying drawings, in which:

FIG. 1 is a side elevation of a preferred embodiment of the present invention.

FIG. 2 is an end elevation of the structure of FIG. 1.

FIG. 3 is a section through a blood vessel showing a tumor reducing the size of the blood vessel.

FIG. 4 is a view similar to FIG. 3 showing one of the steps of the method of inserting the stent of the present invention.

FIGS. 5 and 6 are serial views showing further steps in the method illustrated in FIG. 4.

FIG. 7 is a view similar to FIG. 6 showing three stents having been placed in the blood vessel in accord with another embodiment of the invention.

FIG. 8 is a view similar to FIGS. 6 and 7 showing four stents being placed in a blood vessel in overlapping fashion, in accordance with a further embodiment of the method of the present invention.

FIG. 9 is a side elevation of a sheath used in the method of inserting the stent of the present invention.

FIG. 10 is a sectional view of the proximal end of the sheath showing the stent being placed into the

sheath as a part of the method of inserting the stent of the present invention.

Referring now more particularly to the drawings, there is illustrated in FIG. 1 a side elevation of a preferred embodiment of the stent 9 of the present invention which includes a length 10 of stainless steel wire formed in a closed zig-zag configuration. The wire is closed by a sleeve 11 which is welded to or tightly squeezed against the ends of the wire to produce the endless configuration. Referring to FIG. 4, the stent is shown in a resiliently compressed first shape wherein the straight sections 12 are arranged side-by-side and closely adjacent one another.

The straight sections 12 of the stent are joined by bends 13 which are relatively sharp. Thus, in one specific embodiment of the invention, the bends 13 are at a radius of no more than 0.2 cm. This specific embodiment of the invention includes wire 10 which is stainless steel of 0.046 cm (0.018 inches) O.D. The stent is resiliently expandable from the compressed first shape of FIG.4 into a second shape illustrated in FIGS.1, 2 and 6, wherein the straight sections 12 press against the walls of passageway to maintain the passageway open. FIG.2 shows the end view of the stent in its expanded second shape. As illustrated in FIG. 2, the stent has generally a circular configuration or a cylindrical configuration when it is in its second expanded shape.

In order to practice the method of inserting the stent of this invention, the stent is compressed into the first shape illustrated in FIG. 10 and is placed within a tubular cartridge 15 (FIG. 10). The cartridge 15 is inserted into the recess 16 in the adapter 17 of the sheath 20. The stent is then advanced through the sheath 20 by means of a flat-ended pusher 21. Thus in one specific embodiment of the invention, the flat-ended pusher was made of 8 French polyethylene tubing, although a flat-ended flexible metal rod is preferred. When the stent 10 reaches the end of the sheath as shown in FIG. 4, the flat-ended pusher is held while the sheath is withdrawn as shown in FIG. 5. This frees the stent, allowing it to expand and hug the vessel wall as shown in FIG. 6. If desired and if necessary for the particular situation, further stents can be added and can be placed in the blood vessel in the same fashion as above described. Thus in FIG. 7, an additional two stents are located one longitudinally of the first stent in the blood vessel and the other overlapping the first stent while in FIG. 8, four overlapping stents are used.

In tests of the invention, endovascular stents were designed and built in two sizes (5.5 cm long x 4 cm diameter fully expanded; 3.0 cm long x 2.5 cm diameter fully expanded) from stainless steel wire 0.046 cm (0.018 inches) formed in a zig-zag pattern. They were placed for varying periods of time in the jugular vein, inferior vena cava and abdominal aorta of five dogs (see Table I below) and evaluated with regard to ease of use, dilating force, migration, patency, thrombogenicity, and local vascular changes.

Five adult, mongrel dogs (18-27 kg) were used in the study. They were anesthetized with i.v. sodium pentobarbital (Nembutal; 30 mg/kg) and the jugular vein, femoral vein, and femoral artery were surgically isolated. An incision was made in the vessels and a 8 French Teflon sheath containing an 8 French Teflon catheter with a taper-tip was inserted and under fluoroscopic monitoring advanced just beyond the area of interest. The stent was compressed and placed within a Teflon cartridge which fits inside the adaptor of the 8 French sheath. The 8 French catheter was removed, the cartridge was placed in the sheath adaptor, and the stent was advanced through the sheath with flat-ended 8 French polyethylene tubing. When the stent reached the end of the sheath, the polyethylene tubing was held while the sheath was withdrawn. This freed the stent allowing it to expand and hug the vessel wall. In certain cases, stents were placed one inside another and/or one after another (Table I). Following placement, angiograms were made immediately, after one week, and then at monthly intervals to document stent position and vascular anatomy. The dogs were euthanized at the end of the study by exsanguination under deep Nembutal anesthesia, and a complete necropsy was performed.

TABLE I: Summary of vascular stent placement in five dogs.

Dog # (Wt)	Stent Size (Number Used)	Vascular Placement	Duration
416	5.5 cm (5)	Two placed one inside the other in abdominal aorta (AA) bridging the celiac, cranial mesenteric, and right renal arteries	1 month
		Two placed one inside the other in superior vena cava (SVC) at level of right atrium	
		One placed in the inferior vena cava (IVC) bridging both renal veins	
	3.0 (3)	One placed in right jugular 8 cm above SVC, and two placed one inside the other in left jugular 8 cm above SVC	
355	5.5	One placed in AA bridging the celiac, cranial mesenteric, and right renal arteries	3 months
		Two placed one inside the other in IVC bridging both renal veins	
	3.0 (3)	Two placed one inside the other in SVC at level of right atrium, and one placed 2.3 cm above the right atrium	
354	5.5 (2)	One placed in AA bridging the cranial mesenteric and both renal arteries	4 months
		One placed in IVC bridging both renal veins	
505	5.5 (5)	Four placed one after another in AA beginning at diaphragm (T11) and ending at L5	5 months
		One placed in IVC at level of diaphragm	
	3.0 (3)	One placed inside last long stent in AA at level of L4-L5	
		Two placed one after another in IVC between the hepatic and renal veins	

No difficulties were encountered in the placement of the endovascular stents. They were easy to use and could be placed one inside another and/or one after another. The expansile strength of the stents was found to be dependent on stent length, diameter of stent wires, the number of folds in the wire of each stent, and the number of stents placed one inside another. Specifically, expansile force increased with decreased length, increased stent wire diameter, increased number of wire folds, and increased number of

stents used.

Angiograms made of the stented vessels showed no flow defects, luminal narrowing, or occlusion. Blood vessels bridged by the stents remained patent and showed no indication of narrowing even after six months. No migration was noted with 29 of the 30 stents placed. One long stent (5.5 cm) placed alone in the inferior vena cava migrated approximately 2 cm cranially during the first week following placement, but no further movement occurred and no complications were encountered because of this migration.

Postmortem examinations showed the endothelial proliferation occurred around the stents where the wires contacted the vessel wall. By four weeks following placement, venous stents were almost completely (80%) covered by cell growth while aortic stents were just beginning (30%) to be incorporated. By 12 weeks, all stents were covered with endothelium where the wires contacted the vessel wall. No growth was noted on wire segments that bridged side branches even after 6 months. In addition, no erosion of the vascular walls was noted, and no clot formation was seen on any of the stents.

Percutaneous expandable endovascular stents can be made of various diameters and lengths from stainless steel wire formed in a zig-zag pattern. They are easy to place percutaneously in veins and arteries and do not require the use of ice water or hot saline as do nitinol coils (2, 3). The dilating force of the stent can be controlled by manipulation of wire size, number of wire folds, and stent length. Expansion force increases with larger wire, but so does the size of the collapsed stent which necessitates use of a larger sheath for placement. Increasing the number of wire folds and decreasing the stent length also increase the dilating force. Therefore, stainless steel vascular stents can be tailor-made with regard to length, diameter, and expansion force.

Multiple stents can be employed depending on the circumstance. If the vessel of interest is longer than one stent, several stents can be placed one after another with slight overlap at the ends. In addition, if the expansion strength of one stent is not sufficient, several stents can be placed one inside another to increase the dilating force at a specific point.

Following placement in a blood vessel, the stent gradually becomes incorporated into the vascular wall by endothelial proliferation around the wires where they contacted the wall. This is similar to what has been noted in other studies where metal wire has been placed in the vascular system (2, 3, 4). Radiographic studies indicated that by one week after placement of the stent, sufficient endothelial proliferation had occurred to prevent migration, but during this first week, displacement was possible although not probable. After being in place for one month, the venous stents were approximately 80% encased by endothelium while the aortic stents were only about 30% encased. This difference is probably due to the greater flow and pressure in the aorta. By three months, all stent wires contacting the vessel wall were completely encased in endothelium. This incorporation into the vascular wall reduces thrombogenicity (3), but no clot was found even on the bare wires after 6 months. No cell growth was noted on any of the wire segments not in contact with the vascular wall, e.g., where stents bridged side branches. This observation corresponds with previous reports on the use of endovascular stainless steel wires (4). Therefore, the stents can bridge other vessels without occluding them or producing luminal narrowing at the branch points. This has not been reported for other types of endovascular stents (2, 3). Thus it appears that the stainless steel stents can be placed anywhere in the vascular system that will accomodate them. No luminal narrowing was noted in the stented vessels even after six months. This differs from the nitinol endovascular stents which have been shown to product luminal narrowing within 4 weeks due to fibrin deposition on the stent wires (1, 2, 3).

No clot formation was found on any of the stents at the time they were removed. This is similar to previously reported results (2, 3). No vascular erosion was seen probably because the vessels were normal and able to expand thus reducing the force of the stent wires against the vacular wall.

Results from this evaluation indicate that these stents should find various clinical applications. These may include re-establishment of flow in veins compressed by neighboring tumor (superior vena cava syndrome), maintenance of vascular patency after percutaneous balloon dilations, and correction of incomplete, long, irregular vascular stenosis. In additon, it may be possible to use these stents in other systems such as the respiratory, biliary, and urinary tracts to reinforce collapsing structures from extrinsic compression from neoplasm, maintain the dilatation of a balloon dilated segment of ureter, urethra, or bowel, aortic dissection, aortic aneurysm, and localization of a chronic puncture site.

Claims

1. A stent (9) comprising a single length of wire formed into a closed zig-zag configuration consisting of an endless series of straight sections (12) joined by a plurality of bends (13), wherein the stent is resiliently depressible into a smaller first shape in which all of the straight sections are arranged side-by-side and closely adjacent one another for insertion into a passageway with the bends having a

stress therein, and wherein the stent is resiliently expandable by release of said stress into a second shape in which all of the straight sections define a generally circular or cylindrical configuration for pressing against the wall of the passageway to maintain it open.

2. In combination, the stent of Claim 1 and a tubular cartridge (15) having said stent (9) therein, said stent being resiliently depressed into said smaller first shape.

3. The combination of Claim 2 additionally comprising a sheath (20) having a lumen therethrough, said sheath having an adapter recess arranged coaxially with said lumen and enlarged in size relative to said lumen, and flexible member (21) having a closed end and having an outer size sufficiently small to fit within said sheath yet sufficiently large to push said stent (9) out of said sheath.

4. The stent of Claim 1 wherein said wire is stainless steel of 0.046 cm (0.018 inches) O.D.

5. The stent of Claim 4 wherein said stent in its second shape is 5.5 cm long and 4 cm in diameter.

6. The stent of Claim 4 wherein said stent in its second shape is 3.0 cm long and 2.5 cm in diameter.

7. The stent of Claim 4 wherein said bends are relatively sharp and are at a radius of no more than 0.2 cm.

Revendications

1. Ecarteur (9) comprenant un seul tronçon de fil métallique ayant une configuration sinueuse fermée constitué d'une série sans fin de tronçons rectilignes (12) reliés par plusieurs coudes (13), l'écarteur pouvant être replié élastiquement à une première configuration de petite dimension dans laquelle tous les tronçons rectilignes sont placés côte à côte et très près les uns des autres afin que l'écarteur puisse être introduit dans un passage alors que les coudes sont soumis à une contrainte, l'écarteur pouvant se dilater élastiquement par suppression de la contrainte et prenant une seconde configuration dans laquelle tous les tronçons rectilignes délimitent une configuration circulaire ou cylindrique de façon générale afin que l'écarteur repousse la paroi du passage et maintienne celui-ci sous forme ouverte.

2. En combinaison, l'écarteur de la revendication 1 et une cartouche tubulaire (15) dans laquelle est placé l'écarteur (9), l'écarteur étant replié élastiquement à sa première configuration de petite dimension.

3. Combinaison selon la revendication 2, comprenant en outre une gaine (20) ayant une ouverture la gaine ayant une cavité d'adaptateur disposée coaxialement à l'ouverture et de dimension agrandie par rapport à la lumière, et un organe flexible (21) ayant une extrémité fermée et dont la dimension externe est suffisamment petite pour qu'il se loge dans la gaine mais suffisamment grande pour qu'il puisse repousser l'écarteur (9) en-dehors de la gaine.

4. Ecarteur selon la revendication 1, dans lequel le fil métallique est formé d'acier inoxydable et a un diamètre externe de 0,046 cm (0,018 pouce).

5. Ecarteur selon la revendication 4, dans lequel l'écarteur, lorsqu'il a sa seconde configuration, a une longueur de 5,5 cm et un diamètre de 4 cm.

6. Ecarteur selon la revendication 4, dans lequel, lorsqu'il a sa seconde configuration, l'écarteur a une longueur de 3,0 cm et un diamètre de 2,5 cm.

7. Ecarteur selon la revendication 4, dans lequel les coudes sont relativement aigus et ont un rayon qui ne dépasse pas 0,2 cm.

Ansprüche

1. Stent (9) bzw. medizinisches Gerät zur Gefäßaufweitung, aufweisend ein Einzeldrahtstück, welches in eine geschlossene Zickzack-Gestalt geformt ist, die aus einer endlosen Aneinanderreihung von geraden

Abschnitten (12) gebildet ist, die über eine Mehrzahl von Biegungen oder Biegestellen (13) verbunden sind, wobei der Stent in eine erste, kleinere Gestalt nachgiebig zusammendrückbar ist, in welcher alle geraden Abschnitte zwecks Einführung in einen Durchgang seitlich nebeneinanderliegend und dicht zu einander benachbart angeordnet sind, wobei die Biegestellen unter Spannung stehen, und wobei der Stent durch Freigabe der Spannung in eine zweite Gestalt nachgiebig aufweitbar ausgebildet ist, in welcher alle geraden Abschnitte einen im wesentlichen kreisförmigen oder zylindrischen Aufbau zwecks Anpressung gegen die Wand des Durchganges festlegen, um diesen offen zu halten.

2. Kombination eines Stents nach Anspruch 1 und einer rohrförmigen den Stent (9) enthaltenden Patrone (15), wobei der Stent in seine erste, kleinere Gestalt elastisch zusammengedrückt ist.

3. Kombination nach Anspruch 2, zusätzlich aufweisend einen Mantel (20) mit einem durch ihn hindurchgehenden Durchgang, wobei der Mantel eine Adapterausnehmung aufweist, die koaxial zu dem Durchgang und in ihrer Größe im Vergleich zum Durchgang größer ausgebildet ist, und aufweisend einen flexiblen Teil (21), der ein abgeschlossenes Ende und eine äußere Größe aufweist, die ausreichend klein, damit er in den Mantel paßt, jedoch ausreichend groß ist, um den Stent (9) aus dem Mantel herauszustoßen.

4. Stent nach Anspruch 1, dadurch gekennzeichnet, daß der Draht aus rostfreiem Stahl mit einem Durchmesser von 0,046 cm (0,018 inches) besteht.

5. Stent nach Anspruch 4, dadurch gekennzeichnet, daß der Stent in seiner zweiten Gestalt 5,5 cm lang ist und einen Durchmesser von 4 cm hat.

6. Stent nach Anspruch 4, dadurch gekennzeichnet, daß der Stent in seiner zweiten Gestalt 3 cm lang ist und einen Durchmesser von 2,5 cm hat.

7. Stent nach Anspruch 4, dadurch gekennzeichnet, daß die Biegestellen relativ spitzwinklig ausgebildet sind und einen Radius von nicht mehr als 0,2 cm aufweisen.

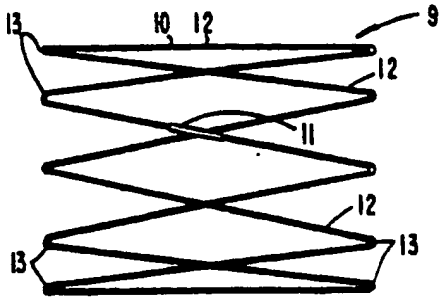


Fig.1

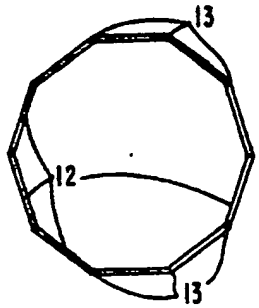


Fig.2

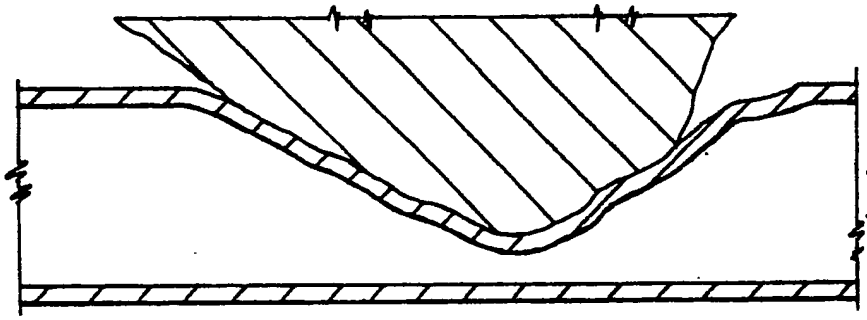


Fig.3

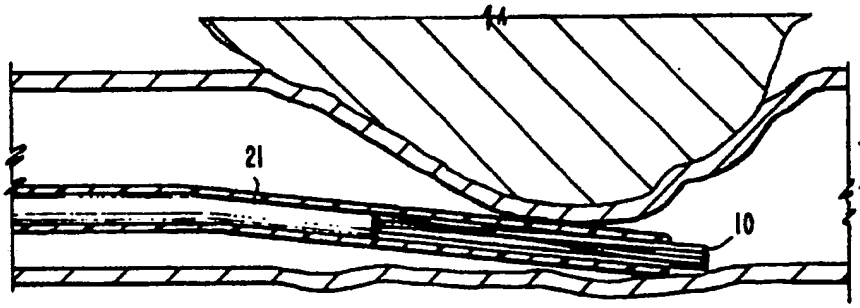


Fig.4

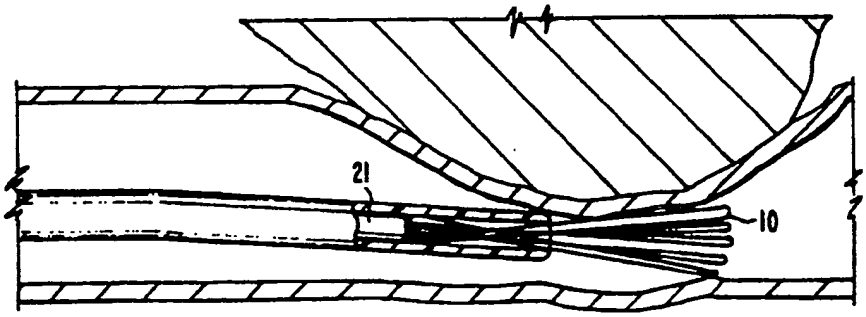


Fig.5

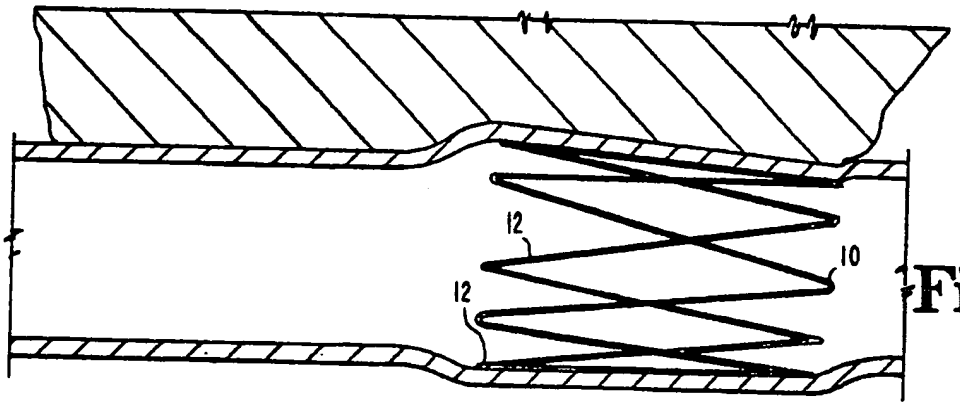


Fig.6

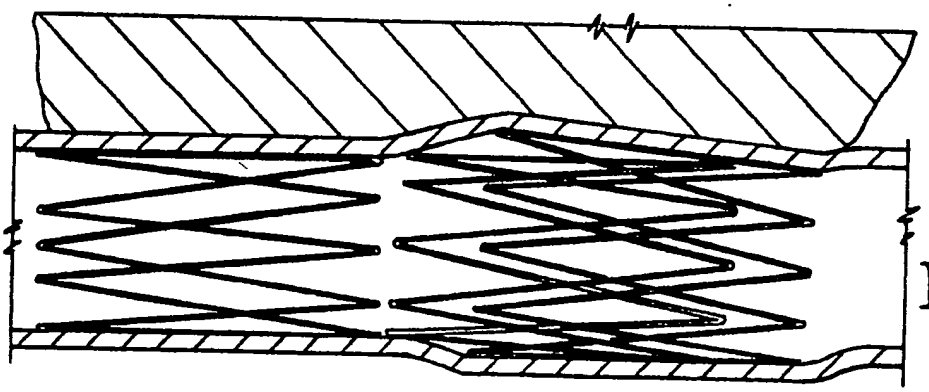


Fig.7

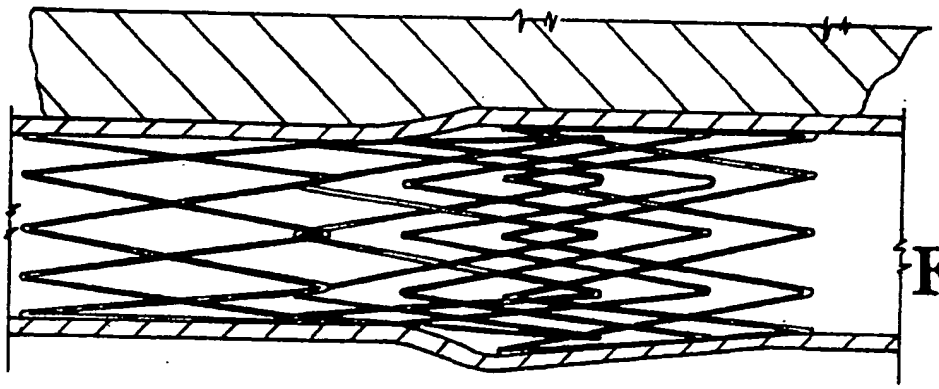


Fig.8

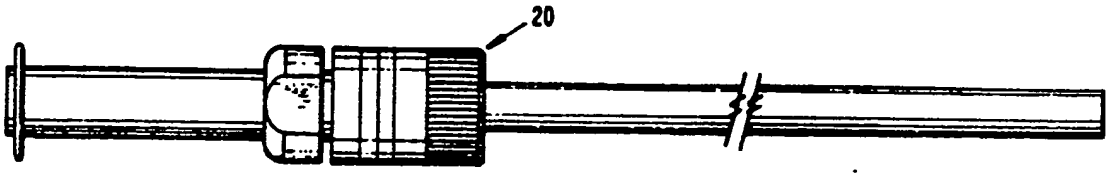


Fig.9

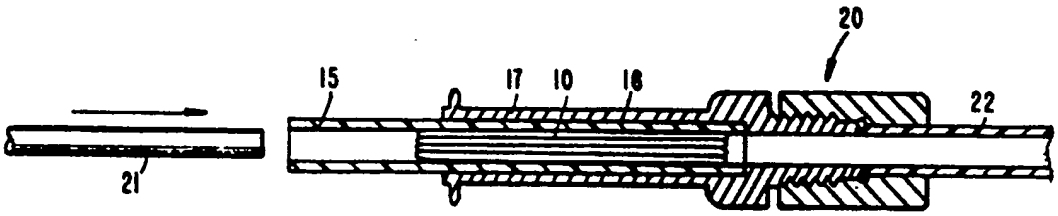


Fig.10

Chapter 30

OVERVIEW OF INTRAVASCULAR STENTS

Julio C. Palmaz

Charles Dotter faced skepticism because many of his brilliant ideas were far ahead of their time. His visionary power led him to conceive of intravascular stenting when percutaneous angioplasty was itself in an embryonic stage. His first paper on percutaneous stenting was published 20 years ago.[5] However, interest in percutaneous stenting did not gain momentum until large series of balloon angioplasty procedures indicated a relatively high proportion of failures.[9]

The skepticism and indifference toward intravascular stenting were due to the lack of available knowledge to support the theory that mechanical scaffolding of a stenotic lumen could result in long-term vessel patency. Extrapolation from classical surgical concepts suggests reasons why vascular stents would not work. For example, foreign bodies tend to migrate, perforate, and create chronic inflammatory reactions; therefore an intravascular metallic stent could cause rupture, fistula, aneurysm formation, or other serious complications. Compliance mismatch between the arterial wall and an unyielding stent could create intimal hyperplasia similar to that occurring at anastomotic sites.[20] By serving as a nidus for thrombus formation, prosthetic material could lead to occlusion or distal embolization. Furthermore, hemodynamic alterations induced by stenting could create accelerated atherosclerosis, stenosis, and ultimate occlusion. Instead, experiments in laboratory animals indicated surprisingly different results. Both medium and large size vessels demonstrated remarkably good tissue tolerance to metal stents.[14,17,23] Stents of varied designs were covered with endothelialized intimal tissue within days to weeks, providing protection against low-flow thrombosis, the main problem affecting surgical synthetic grafts. The rapid incorporation of stents into the thickness of the arterial wall may explain the relatively tenuous intimal hyperplasia covering the lumen of most stents.[17,18] Also fascinating was the rapid healing of stents in atherosclerotic vessels. Not only did the stent incorporate in diseased vessel wall as quickly as in normal vessels but the tissue covering the stent did not undergo atherosclerotic changes despite the continuation of atherogenic diets.[15] The stable inner surface of stented vessels may allow new tissue growth, preventing surface irregularity, turbulence, platelet deposition, and other events that can result in vessel occlusion. In addition to the obvious beneficial effects of the mechanical scaffolding, stenting provides a new framework for the diseased vascular tissues to reorganize into functional status.

The recent explosion of percutaneous vascular techniques is the result of the need for safer less costly alternatives to surgery. Despite their appeal, some of these advancements such as balloon angioplasty remain underutilized in the peripheral vasculature.[7] On the other hand, percutaneous transluminal coronary angioplasty (PTCA) reached full potential but its results were clouded by a restenosis rate of 30% and an abrupt closure rate around 3%. In this respect, percutaneous stenting may improve results of these procedures by preventing both acute and delayed failures. For example, stenting may result in a reduction of the need for standby surgery, which accounts for a significant proportion of the cost of PTCA.[10]

TYPES OF VASCULAR STENTS

Regardless of type, all intravascular stents are introduced through a small arteriotomy and are expanded to functional diameter at the intravascular target site. The expanded stent is initially fixed in place by frictional force resulting from the expansile strength of the stent and the elastic recoil of the vessel wall.

To date, intravascular stents can be classified according to their mechanism of action into three types:

1. Thermal memory stents
2. Spring-loaded stents
3. Plastic stents

Thermal memory stents

Thermal memory stents are fabricated of alloys of nickel and titanium known as *nitinol*. These devices change shape when placed in contact with warm blood or saline, adopting a coiled configuration of predetermined diameter.[4,6,22] Although experience in the United States with these devices is limited to laboratory animals, a surprisingly large clinical experience with nitinol coils was reported from the USSR with good results.[16]

Spring-loaded stents

Spring-loaded stents are made of tempered stainless steel alloy wire arranged in a tubular fashion and constrained into a small diameter inside a delivery catheter for introduction into the vascular lumen. At the target site the device is freed from the constraining sleeve and allowed to expand. The final diameter is a point of equilibrium between the residual elasticity of the stent and the elastic recoil of the vessel wall. Examples of spring-loaded stents are the Gianturco stent[23] and the Medinvent stent.[19]

Plastic stents

Plastic stents are made of malleable metal, usually annealed stainless steel. They are expanded beyond their elastic limit by the inflation of a coaxial balloon that simultaneously expands the arterial wall and the stent, pressing the device flush against the dilated vascular surface. The balloon-expandable intravascular stent (BEIS), a continuous slotted metal tube that opens into a mesh, is based on this mode of action. Balloon expandability was adopted in other devices fabricated of malleable metal, including a stent with interdigitating alternating wire windings[6] and a woven metal mesh.[21]

CURRENT USE AND PROSPECTIVE CLINICAL APPLICATION

Stents were successfully used in small series of patients with superior vena cava stenosis.[2] Early human experimental application of stents in Europe in patients with iliofemoral or coronary artery stenosis proved the feasibility of clinical application and stimulated further interest.[19] Emerging data from multicenter trials of BEIS in human iliac and coronary arteries are very promising.[13] However, it will take several years to firmly establish the safety and efficacy of these devices. Elastic recoil is the major limitation of vascular balloon dilatation. Therefore, the achievement of a cylindrical lumen without overdilatation is compelling, provided it is safely and effectively accomplished. Stents hold promise in the prevention of postangioplasty restenosis in the coronary arteries and in the ostia of stenotic renal arteries. They may become the primary therapy in pulmonary artery branch stenosis, where angioplasty is largely ineffective.[12]

Stent dilatation of growing vessels such as in children with pulmonary artery stenosis or aortic coarctation is possible with stents that can be redilated at a later date, after incorporation into the vascular wall.[11] The use of stents in acute aortic dissection[3] is also suggested. Theoretical vascular applications of stents embedded in a thin webbing of elastomers or absorbable materials include the bridging of fusiform or saccular aneurysms and arteriovenous fistulas. Coated stents may be tailored to function as flow restrictors or occluders of large vessels. Stents, lasers, atherectomy devices, and other developing forms of vascular interventions will not displace each other. On the contrary, they are likely to be used conjunctionally to improve results. However, as stents and other invasive techniques develop, some serious territorial conflicts occur between medical specialties currently involved in vascular therapeutics.[1] Undoubtedly, involvement in techniques such as stenting requires expertise in the clinical aspects of vascular disease, noninvasive hemodynamic assessment, dexterity in catheter manipulation, and knowledge of x-ray equipment and radiation physics and safety.

In addition, placing an endovascular stent, or performing some of the more advanced vascular therapeutic techniques requires a long-term commitment in the follow-up of the patient. Such commitment may require profound changes in the patterns of current interventional radiology practice and allow a better physician-patient relationship.

REFERENCES

1. Becker GJ, Katzen BT: Perspective. Peripheral angioplasty and the newer circulatory interventions: whose responsibility? AJR 150:1235, 1988.
2. Charsangavej C, Carrasco CH, Wallace S, et al.: Stenosis of the vena cava: preliminary assessment of treatment with expandable metallic stents. Radiology 161:295, 1986.
3. Charsangavej C, Wallace S, Wright KC, et al.: Endovascular stent for use in aortic dissection: an in-vitro experiment. Radiology 157:323, 1985.
4. Cragg A, et al.: Non-surgical placement of arterial endoprostheses: a new technique using nitinol wire. Radiology 147:261, 1983.
5. Dotter CT: Transluminally placed coilspring endarterial tube grafts, long term patency in canine popliteal artery. Invest Radiol 4:327, 1969.
6. Dotter CT, Buschmann RW, McKinney MK, et al.: Transluminally expandable nitinol coil stent grafting: preliminary report. Radiology 147:259, 1983.
7. Doubilet P, Abrams HL: The cost of underutilization: percutaneous transluminal angioplasty for peripheral vascular disease. N Engl J Med 310:95, 1984.
8. Duprat G, Wright KC, Charsangavej C, et al.: Flexible balloon-expanded stent for small vessels. Radiology 162:276, 1987.
9. Holmes DR, Vliestra RE, Smith HC, et al.: Restenosis after percutaneous transluminal coronary angioplasty (PTCA): a report from the PTCA Registry of the National Heart, Lung and Blood Institute. Am J Cardiol 53:77C, 1984.
10. Kouchoukos N: Percutaneous transluminal coronary angioplasty: a surgeon's view. Circulation 72:1144, 1985.
11. Morrow R, et al.: Post-healing re-dilatation of balloon-expandable intraortic stents: experimental evaluation, presented at the sixty-first meeting of the AHA, Washington DC, November 1988.
12. Mullins CE, O'Laughlin M, Vick W, et al.: Implantation of balloon-expandable intravascular grafts by catheterization in pulmonary arteries and systemic veins. Circulation 77:188, 1988.
13. Palmaz JC, Richter GM, Noeldge G, et al.: Intraluminal stents in atherosclerotic iliac artery stenosis: preliminary report of a multicenter study. Radiology 168:727, 1988.
14. Palmaz JC, Sibbitt RR, Reuter SR, et al.: Expandable intraluminal graft: a preliminary study. Radiology 156:73, 1985.
15. Palmaz JC, Windeler SA, Garcia F, et al.: Atherosclerotic rabbit aortas: expandable intraluminal grafting. Radiology 160:723, 1986.
16. Rabkin J: Revascularization par implantation d'une prosthese radioendovasculaire: radiologie interventionnelle en pathologie cardiovasculaire. International Congress, Toulouse, France, February 1988.
17. Rousseau H, Puel J, Joffre F, et al.: Self expanding endovascular prosthesis: an experimental evaluation. Radiology 164:709, 1987
18. Schatz RA, Palmaz JC, Tio FO, et al.: Balloon-expandable intracoronary stents in the adult dog. Circulation 76:450, 1987.
19. Sigwart V, et al.: Intravascular stents to prevent occlusion and restenosis after transluminal angioplasty. N Engl J Med 316:701, 1987
20. Strandness DE: Angioplasty devices will not prevent restenosis. Cardio 4:116, 1988.
21. Strecker EP, Berg G, Weber H, et al.: Experimentelle Untersuchungen mit einer neuen perkutan einfuhrbaren und aufdehnbaren Gefabendoprosthese. Fortschr Rontgenstr 147:669, 1987
22. Sugita Y, Shimomitsu T, Oku T, et al.: Non-surgical implantation of a vascular ring prosthesis using thermal shape memory Ti Ni alloy (nitinol wire). ASAIO Trans 32:30, 1986.
23. Wright KC, Wallace S, Charsangavej C, et al.: Percutaneous endovascular stents: an experimental evaluation. Radiology 156 (9), 1985

Flexible Balloon-expanded Stent for Small Vessels

Work in Progress[1]

Gerard Duprat, Jr., MD, FRCP(C)[2]
Kenneth C. Wright, PhD
Chusilp Charnsangavej, MD
Sidney Wallace, MD
Cesare Gianturco, MD

A new type of flexible, balloon-expanded, stainless steel stent was designed for introduction into small vessels subject to motion. Four stents placed in four dogs were patent at follow-up (4–8 weeks). A fibrocellular proliferation involving the intima and media was responsible for a 20%–25% luminal narrowing observed in all vessels with stents. The stent has longitudinal flexibility, which should permit its insertion into small peripheral, visceral, and coronary arteries.

Index term: Arteries, grafts and prostheses

Radiology 1987; 162:276–278

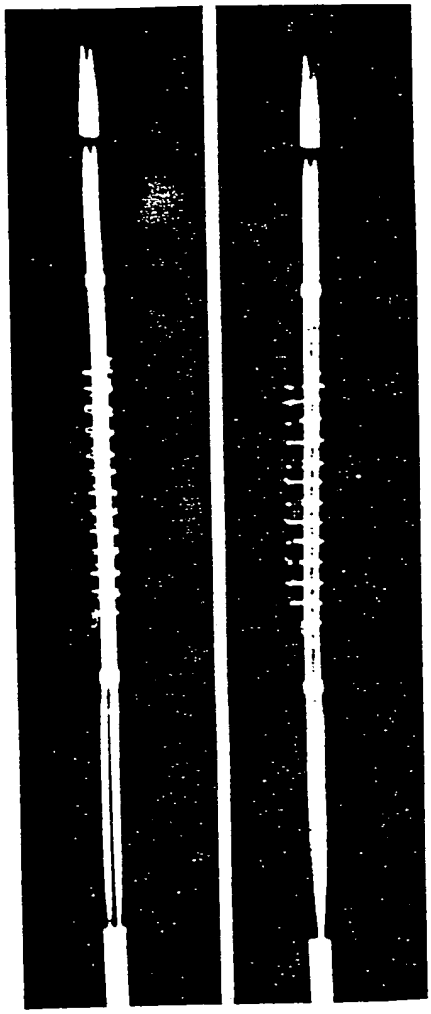
ENDOVASCULAR stents may be useful for correcting severe intimal dissection or recurrent stenosis after angioplasty of small vessels. Many types of endovascular stents and prostheses are described in the literature, but few have been inserted in vessels smaller than 5 mm and none have longitudinal flexibility. Only two of six coiled, stainless steel wire stents (3.5 mm in diameter) placed in canine arteries remained patent at follow-up (1). The insertion of two nitinol wire coils (5 mm in diameter) resulted in thrombosis of one coil after 2 weeks and significant narrowing of the lumen within the other coil after 13 weeks (2). Self-expanding, zigzag (Gianturco) metallic stents inserted in vessels smaller than 5 mm remained patent provided the ratio of stent/recipient vessel diameter was smaller or equal to 1.2 (3).

This report describes a new type of flexible, balloon-expanded endovascular stent. The technique of insertion and the preliminary results in vessels smaller than 5 mm in diameter are presented.

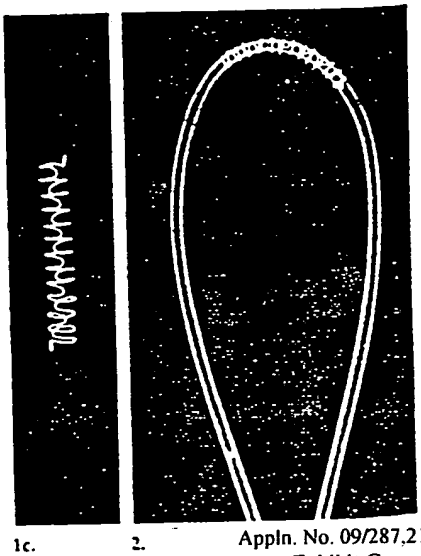
Materials and Methods

The flexible, balloon-expanded stents were made of surgical suture wire (0.006-inch) wrapped cylindrically, with bends adopting a sequential U and inverted U configuration every 360° (Fig. 1). The stents were wrapped tightly around a collapsed angioplasty balloon (25 mm long and 2.5 mm in diameter when fully inflated). The angioplasty balloon–stent unit was 2 mm in diameter; when fully expanded, stents measured 15 mm long and 2.5 mm in diameter. To evaluate longitudinal flexibility, the stents were wrapped around 5-F polyethylene tubing that had been bent into various configurations (Fig. 2).

Four adult mongrel dogs (20–24 kg) were anesthetized with an intravenous injection of sodium pentobarbital (30 mg/kg). After heparin administration (100 U/kg), a vessel with a diameter similar to that of the stent was selectively catheterized using a 5-F polyethylene catheter; the catheter was introduced through a carotid arteriotomy. Catheter exchange was performed over a wire guide (0.018 inch), and the angioplasty balloon–stent unit was advanced to the area of interest. The balloon was inflated to maximal pressure for 1 minute. This was repeated two to three times until good stent expansion was observed fluoroscopically. The angioplasty catheter was withdrawn while negative pressure was applied to the balloon. Angiography was performed before and immediately after stenting, at 1 week, 4 weeks, and at the end of the study. One stent was inserted into the gluteal, saphenous, superficial femoral, or deep femoral artery



1a. 1b.



1c. 2.

Figures 1, 2. (1) Low-kV radiographs with two-fold magnification. (a) Angioplasty balloon–stent unit in the collapsed state. The stent fits tightly around the angioplasty balloon between the metallic markers. (b) Angioplasty balloon–stent unit after inflation to maximal pressure. Complete expansion of the stent is seen. (c) Expanded stent after the angioplasty balloon is withdrawn. (2) Low-kV radiograph. After balloon expansion, the stent has been mounted on a 5-F, bent, polyethylene catheter.

[1] From the Division of Diagnostic Imaging, Department of Diagnostic Radiology, Box 57, University of Texas, M.D. Anderson Hospital and Tumor Institute at Houston, 6723 Bertner Ave., Houston, TX 77030. From the 1986 RSNA annual meeting. Received July 30, 1986; accepted August 27. Supported in part by the John S. Dunn Research Foundation and the George Alfred Cook Memorial Fund. Address reprint requests to K.C.W.

[2] Current address: Department of Radiology, Hotel Dieu de Montreal, Canada.

Figure 3. Collimated views of conventional radiograph (a) and superficial femoral arteriogram (b) obtained immediately after stent insertion in the left saphenous artery. The stent is fully expanded, and the vessel lumen is patent. Note dilatation of the artery at the site of balloon inflation (arrows, b). (c) Arteriogram obtained 6 weeks after insertion demonstrates a 25% luminal narrowing within the stent. The stent diameter is unchanged, and there is slight luminal narrowing at the origin of one small side branch.

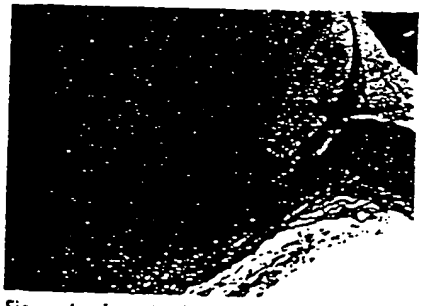


Figure 4. Longitudinal section of a stented artery 6 weeks after placement. (Hematoxylin and eosin, ×100.) Note proliferation of intima and disruptions of the internal elastic lamina (open arrows). There is also a fibrocellular proliferation involving the media. Double-headed arrow indicates the endothelium-lined space occupied by the stent wire. The side branch seen to the right of this space is patent.

(one stent per dog). The dogs were killed by exsanguination while under deep sodium pentobarbital anesthesia at 4 weeks (two dogs), 6 weeks (one dog), or 8 weeks (one dog). The vessels containing the stents were resected and examined grossly and histologically.

Results

These flexible stents were easily expanded to their full diameter (2.5 mm) and did not change in diameter during the follow-up period (4–8 weeks). All stents were patent immediately after insertion. A 20%–25% luminal narrowing was observed in all stents at the end of the follow-up period (Fig. 3). No vessel occlusion or stent migration was noted. Blood vessels bridged by the stents remained patent with no evidence of narrowing, except in one case in which a small branch narrowed slightly at its origin (Fig. 3c).

Histologic examination showed multiple disruptions of the internal elastic membrane and occasional intimal splits with associated areas of intimal hemorrhage (Fig. 4). A moderate proliferation of intimal cells was noted, as was a cellular proliferation involving the media. These proliferations were predominantly fibrocellular. All stent wires were embedded in intimal proliferation and covered by a thin endothelial layer on the luminal surface. No thrombosis was seen, and the adventitia remained intact.

Discussion

Our results demonstrate that this type of stent can easily be introduced into arteries less than 5 mm in diameter and that complete stent expansion can be achieved with an angioplasty balloon. Successful insertion required gentle introduction of the angioplasty balloon-stent unit at the arteriotomy site to prevent the stent from slipping off the balloon. Three balloon inflations at maximal pressure were necessary to achieve full stent expansion and avoid difficulty in withdrawing the balloon.

One definite advantage of this balloon-expanded stent is its longitudinal flexibility. The tubular mesh described by Palmaz et al. (4) is also expanded by an angioplasty balloon, but it lacks longitudinal flexibility. We have also succeeded in inserting the self-expanding zig-zag stents into straight vessels smaller than 5 mm, but this stent has no longitudinal flexibility either (3). This flexibility is important if stents are to be inserted into small, continuously moving vessels with numerous curves and bends, such as the coronary arteries. Flexible stents should also be useful in extremity, gastrointestinal tract, and renal arteries.

Angioplasty often results in splitting of the intima to the level of the internal elastic membrane and intimal hemorrhage (5, 6) as was seen in this study. In addition, the stents remained patent with no occlusion of side branches, but 20%–25% luminal narrowing occurred in all stented vessels. This was attributable to a fibrocellular proliferation involving both the intima and the media, which may represent stent-enhanced continuation of the vascular repair process initiated by angioplasty. The hemodynamic significance and the long-term (>8 weeks) outcome of these changes are not known. Further, these results were obtained in normal vessels, and additional studies are needed to determine the effects of balloon-expanded stents in experimentally induced stenotic lesions. ■

Acknowledgments: The authors thank Raquel Collins, B.S., and Irene Szwarc, R.T., for their expert technical assistance, and Margret Meza for her secretarial help in the preparation of this manuscript.

References

1. Dotter CT. Transluminally-placed coil-spring endarterial tube grafts: long term patency in canine popliteal artery. Invest Radiol 1968; 4:329–332.
2. Cragg AH, Lund G, Rysavy JA, Salomanowitz E, Castaneda-Zuniga WR, Amplatz K. Percutaneous arterial grafting. Radiology 1984; 150:45–49.
3. Duprat G, Wright KC, Charnsangavej C, Wallace S, Gianturco C. Self-expanding metallic stents for small vessels: an experimental evaluation. Radiology (in press).
4. Palmaz JC, Sibbitt RR, Reuter SR, Tio FO, Rice WJ. Expandable intraluminal graft: a preliminary study. Radiology 1985; 156:73–77.
5. Zollikofer CL, Chain J, Salomanowitz E, et al. Percutaneous transluminal angioplasty of the aorta: light and electron microscopic observations in normal and atherosclerotic rabbits. Radiology 1984; 151:355–363.
6. Block PC, Fallon JT, Elmer D. Experimental angioplasty: lessons from the laboratory. AJR 1980; 135:907–912.

Recurrent Female Pelvic Cancer: Assessment with Transrectal Ultrasonography[1]

Clive A. Meanwell, MB, ChB
Edward B. Rolfe, MB, ChB, FRCR
George Blackledge, MD, PhD, MRCP
Melvyn F. Docker, MSc
Frank G. Lawton, MB, ChB, MRCOG
John J. Mould, FRCR, MRCOG

Fifty-two women with symptoms or signs suggesting pelvic recurrence of biopsy-proved pelvic cancer were assessed in a prospective trial by clinical examination, transabdominal pelvic ultrasonography (TAU), computed tomography (CT), and transrectal pelvic ultrasonography (TRU). TRU significantly added to the information from TAU in the measurement of abnormalities on the pelvic sidewalls, and to TAU and CT in the measurement of abnormalities in the central and presacral regions of the pelvis. Results of this preliminary study suggest that TRU may provide information complementary to that from CT in women with suspected recurrence of gynecologic cancer.

Index terms: Pelvis, CT, 8.1211 • Pelvis, neoplasms, 8.32 • Pelvis, US studies, 8.1298

Radiology 1987; 162:278—281

THE diagnosis and assessment of recurrent female pelvic cancer is a challenging problem. Precise determination of tumor dimensions and distribution within the pelvis is an essential prerequisite for rational therapy; however, clinical examination is unreliable (1), and restaging laparotomy may not be indicated in all cases. Transabdominal pelvic ultrasonography (TAU) and computed tomography (CT) have therefore emerged as important pretreatment investigations (2).

Transrectal pelvic ultrasonography (TRU) was designed to assess localized prostatic cancer (3). Subsequent studies demonstrated that images of other pelvic structures could be obtained using low-frequency endosonic transducers (4); this prompted a previous study, the results of which suggested that TRU may be used in the management of recurrent cervical cancer (5). The aims of the present study were to determine the features on TRU of a variety of recurrent gynecologic cancers and to compare TRU findings with those of clinical examination, TAU, and CT.

Patients and Methods

Fifty-two consecutive patients (median age, 52 years; range, 27–68 years) were entered into this prospective trial. All were referred to St. Chads Hospital or the Queen Elizabeth Hospital between June 1984 and March 1985 with symptoms suggesting pelvic recurrence of biopsy-proved pelvic malignancy. The patients represented a selected group referred from several hospitals to a regional center for cancer treatment. Patients had previously been treated for cervical cancer (30 cases, median time since original treatment 21 months), epithelial ovarian cancer (18 cases, 11 months), endometrial cancer (four cases, 27 months), uterine sarcoma (three cases, 7 months), or bladder cancer (one case, 12 months). Twenty-seven had undergone pelvic surgery (hysterectomy and bilateral salpingo-oophorectomy with or without lymphadenectomy), and 31 had undergone pelvic radiation. Informed consent was obtained from all patients after the nature of the study procedures had been explained.

All patients underwent clinical examinations and TAU; 48 had CT examinations. All patients subsequently underwent TRU examination. Clinical pelvic assessments were performed with patients in the supine position and included abdominal, digital vaginal, rectal, and combined vaginal-rectal examinations. Patients had full bladders for the TAU examinations. Transverse, longitudinal, and oblique scanning was performed with patients supine using 3.5–5-MHz real-time sector transducers coupled to a Hewlett Packard (Andover, Mass.) 77065AR ultrasound (US) scanner. Water enemas were not used.

CT was performed using an International General Electric 8800 CT scanner (Milwaukee) with the dynamic scan option (B7815F dynamic scan software package). Contiguous 1-cm sections were obtained that included the superior margin of the bladder and the level of the pubic symphysis. One hour before CT examination, patients ingested 100–200 ml Gastrografin (10% sodium diatrizoate, 66% meglumine diatrizoate Schering, Burgess Hill, United Kingdom) diluted in 1–2 litres of water (4% solution vol/vol). Immediately before CT, patients were given 20 mg busco-

[1] From the West Midlands CRC Clinical Trials Unit, Clinical Research Block (C.A.M., G.B.), and the Departments of Radiology (E.B.R.) and Radiotherapy and Oncology (J.J.M.), Queen Elizabeth Hospital, Egbaston, Birmingham B15 2TH, United Kingdom; and the University Department of Obstetrics and Gynaecology (F.G.L.) and Department of Physics (M.F.D.), Birmingham Maternity Hospital, Birmingham, United Kingdom. Received February 14, 1986; revision requested April 10; revision received July 28; accepted August 5. Address reprint requests to C.A.M.

Chusilp Charnsangavej, MD • C. Humberto Carrasco, MD • Sidney Wallace, MD
• Kenneth C. Wright, PhD • Kenji Ogawa, MD • William Richli, MD • Cesare Gianturco, MD

Stenosis of the Vena Cava: Preliminary Assessment of Treatment with Expandable Metallic Stents[1]

To test the ability of Gianturco expandable metallic stents to dilate and maintain patency in stenotic venae cavae, stenosis of the inferior vena cava was created in seven mongrel dogs by the percutaneous injection of absolute ethanol into the paravascular retroperitoneal space. Gianturco stents, placed across the stenotic segment, resulted in successful dilatation with improved hemodynamics in four dogs. The stents failed to dilate an occluded vena cava in one dog; in the remaining dogs, stent placement was complicated by early migration and occlusion. Gianturco stents were placed in two patients, one with superior vena cava syndrome and one with retroperitoneal fibrosis that obstructed the inferior vena cava, and resulted in immediate relief of presenting symptoms. These results should be viewed cautiously, but further investigation into the clinical use of the stents is indicated, especially for patients for whom other treatments are difficult.

Index terms: Venae cavae, grafts and prostheses • Venae cavae, stenosis, 569.36

Radiology 1986; 161:295–298

IN recent years, several types of vascular endoprotheses have been developed for vascular uses. Cragg et al. (1) and Dotter et al. (2) used a metallic alloy (nitinol) to form coil grafts; Palmaz et al. (3) developed a balloon-assisted expandable graft with a thin, stainless steel, wire mesh in the wall; and Wright et al. (4) evaluated the expandable metallic stent designed by Gianturco.

The Gianturco expandable metallic stent is constructed of a stainless steel wire bent in a zigzag pattern to form a cylinder. The stent can be compressed and introduced through a Teflon catheter of 8–12 Fr, depending on the caliber of the wire and the diameter of the stent. As the stent is released from the catheter, it expands to its original diameter. The expansile force varies with the caliber of the wire, the diameter and length of the stent, and the number and angle of the bends.

Wright et al. (4), who studied use of the stent in the normal canine vena cava, found that proliferation of the endothelium covered the entire stent after placement. The caval lumen and orifices of caval side branches remained patent during the 6 months of follow-up.

We report our evaluation of the ability of the Gianturco stent to dilate and maintain the patency of experimentally induced stenoses in the vena cava in dogs. We also describe clinical application of the stent in two patients with stenosis of the vena cava caused by tumor encasement or postsurgical and radiation fibrosis.

ANIMAL EXPERIMENT

Materials and Methods

Seven normal mongrel dogs, each weighing 20–25.5 kg, were used. Anesthesia was induced and maintained with sodium pentobarbital (30 mg/kg).

The stenotic vena cava was created by percutaneous injection of 20–30 ml of absolute ethanol through a 22-gauge needle into the retroperitoneal space around the inferior vena cava below the renal veins. Cavography of the inferior vena cava was used to guide the injection and was performed via the femoral or jugular vein approach. We attempted to place the needle tip in the caval wall or the paravascular space rather than in the lumen before the ethanol was injected.

A significant stenosis was defined as a 50% decrease in the caval diameter or a pressure gradient across the stenosis of more than two times normal or 5 cm of saline, whichever was greater. In five of the seven dogs, a significant stenosis developed 2 weeks after the injection. In one dog, stenosis occurred at 1 week, but by 2 weeks, the vena cava was occluded. In the remaining animal, a second injection of ethanol was necessary to achieve caval stenosis in 4 weeks.

After a significant stenosis developed, stents were placed across the narrowed segment. Three types of Gianturco stents were used. In the initial four dogs, a single stent or multiple stents of 0.044-cm (0.018-inch) wire, 2 cm in diameter, and 3 cm long were used. To prevent migration, the stent was modified by attaching barbs (Fig. 1a), which allowed the stent to become affixed to the wall of the vessel as it was released from the catheter. For a long stenosis, two stents of similar length were connected by wire struts (Fig. 1b). They provided a greater expansile force than a single long stent and better stabilization. Migration was minimized by releasing the leading stent while the other stent remained in the catheter.

After a 10-F Teflon catheter was positioned at the desired location in the inferior vena cava, the stent was compressed and placed into the hub end. The stent was advanced to the catheter tip with a pusher cable or catheter. To release the stent, the pusher cable was held stable, and the catheter was withdrawn slowly until the stent was completely released and expanded. When multiple stents were placed, an attempt was made to bridge or overlap the adjoining stents. A similar catheter was used to place the barbed stent.

Conventional radiographs of the dogs

From the Department of Diagnostic Radiology, University of Texas, M.D. Anderson Hospital and Tumor Institute, 6723 Bertner Avenue, Houston, TX 77030. From the 1985 RSNA annual meeting. Received March 10, 1986; accepted and revision requested May 1; revision received June 23. Address reprint requests to

Radiology

ADVERTISERS' INDEX

RSNA Advertising Policy

According to the advertising policy of the Radiological Society of North America, the information describing radiological equipment, products, and services offered by vendors in their advertisements should be ethical, educational, professional, of value in furthering the radiologic evaluation and treatment of patients and furthering the education of the radiologists and allied scientists. The guidelines below should be followed for advertising in RSNA journals:

- All advertising must be directed to radiologic diagnosis, therapy, research, continuing education, communication and/or to the professional and managerial roles of radiologists and allied scientists. Advertising material should be consistent with the highest standards of professionalism.
- RSNA reserves the right to reject copy which, in its opinion, is not in good taste, is unprofessional, or is inappropriate for a radiology publication, or offers products or services not in the best interest of the patient or the Society.
- Acceptance of advertising does not mean endorsement by RSNA of the products or services advertised, the advertisers, or the claims made.

RADIOLOGY (ISSN 0033-8419) is published monthly by the Radiological Society of North America, Inc., at 20th and Northampton Sts., Easton, PA 18042. Second class postage paid at Easton, PA. The nonmember subscription rate for the U.S.A., Canada, and Mexico is $95.00 per year. The resident subscription rate is $32.00 per year. The foreign and Pan-American subscription rate is $100.00 per year. Foreign subscription rates (including Canada and the Pan-American Union) require an additional $25.00 for postage. (Air freight is available; rates are furnished on request). Single copies are $11.00 each. Orders for subscriptions, remittances, and change-of-address notices should be sent to Dues and Subscription Department, the Radiological Society of North America Inc., 20th and Northampton Sts., Easton, PA 18042. Subscribers requiring an address change must submit an old mailing label and their new address including the zip code.

Claims for copies lost in the mail are allowed within 90 days of the date of issue. Claims are not allowed for issues lost as a result of insufficient notice of change of address.

Membership in the Radiological Society of North America is by formal application, and an initiation fee is required. Membership information should be secured from the Executive Director, the Radiological Society of North America Inc., Oak Brook Regency Towers, 1415 W. 22nd St., Tower B, Oak Brook, IL 60521. Dues are payable annually in January. In accordance with U.S. postal regulations, $47.50 of active membership dues and $16.00 of member-in-training dues are allocated to a subscription of RADIOLOGY.

THE TWELFTH ANNUAL COURSE
ON

"DIAGNOSTIC ANGIOGRAPHY AND INTERVENTIONAL RADIOLOGY"

MARCH 23-26, 1987
Hotel Inter-Continental
San Diego, California

Sponsored by the:
SOCIETY OF CARDIOVASCULAR &
INTERVENTIONAL RADIOLOGY

P.O. Box 44113
Pittsburgh, PA 15205
(412) 921-2636

Josef Rösch, MD. • Barry T. Uchida, BS • James S. Putnam, MD
• Robert W. Buschman, BS • Robert D. Law, BS • Allen L. Hershey, BS

(1)

Experimental Intrahepatic Portacaval Anastomosis: Use of Expandable Gianturco Stents[1]

Original Gianturco expandable stents and their modifications were used to create an experimental intrahepatic portacaval anastomosis (EIPCA) in 30 young domestic swine without portal hypertension. The study focused on the design of a suitable stent, the technique of its application, and the evaluation of short-term patency of the EIPCA. A stent with a 2.5-cm-long body and wire skirts on both ends was most suitable for EIPCA creation. Well-positioned stents shunted most of the portal blood in the inferior vena cava circulation and remained patent for 4-6 weeks. Ingrowth of liver parenchyma and abundant proliferation of the intima and connective tissue inside the stent lumen in these rapidly growing animals gradually decreased EIPCA patency, and thrombus formation with diminished blood flow closed them completely.

Index terms: Portal vein • Veins, prostheses

Radiology 1987; 162:481-485

EXPANDABLE stainless steel wire stents designed by Gianturco have been successfully tested in animal experiments as endoprostheses in arterial, venous, and biliary systems and in the tracheobronchial tree (1-3). We tested the original expandable Gianturco stents and their modifications for experimental intrahepatic portacaval anastomosis (EIPCA) and report here the results of the first phase of our study, which focused on the development of a suitable stent, the technique of its application, and evaluation of short-term patency of EIPCA.

MATERIALS AND METHODS

Thirty young domestic swine weighing 16-20 kg were used. Because of the study's orientation to short-term EIPCA patency, no attempts were made to induce portal hypertension. The studies were performed after anesthesia was induced by inhalation of Metofane (methoxyflurane; Pittman-Moore, Washington Crossing, N.J.).

A 5-F Teflon catheter was transhepatically introduced into the portal vein by transperitoneal puncture. Next, the right internal jugular vein was exposed and a 7-F catheter introduced into the inferior vena cava. Venograms of the portal vein and inferior vena cava were then obtained to evaluate the anatomic relation of these veins for selection of the liver puncture site (Fig. 1). Liver puncture was performed with a newly designed transjugular coaxial needle catheter system consisting of a 0.097-cm (0.038-inch) needle, a 5-F Teflon catheter, a 14-gauge metal cannula, and a 10.5-F thin-walled Teflon catheter (4). The liver puncture was made in the first ten animals from a hepatic vein into the left portal branch. In the other 20 swine, the puncture was made directly from the inferior vena cava, and the distal portion of the left portal branch or bifurcation of the portal vein was entered. The transhepatic catheter positioned into the portal vein bifurcation served as a target. Fluoroscopic monitoring in two projections (animals were on a rotating cradle) helped direct the needle for the liver puncture. After

Figure 1. Simultaneously obtained venograms of portal vein and inferior vena cava in steep oblique projection. Arrows indicate optimal site for liver puncture.

the needle entered the portal vein, the 5-F catheter was advanced over the needle into the portal circulation and the needle was exchanged for a 0.097-cm (0.038-inch) safety J guide wire. The puncture system was then withdrawn, and a 45-cm-long, 12-F Teflon sheath was introduced with the help of a well-tapered coaxial catheter and advanced into the inferior vena cava. The sheath was used for dilation of the liver puncture tract, stent application, and balloon stent distention. The liver puncture tract was dilated first with a tapered 10-F Teflon catheter and then with a 10-mm angioplasty balloon catheter. The sheath was then advanced into the portal vein, ready for the stent placement.

The original Gianturco stents were made from 0.046-cm (0.018-inch) wire, 3 cm long and 2 cm in diameter fully expanded, and were used in three swine (Fig. 2a). Three types of modified stents 4-6.5 cm long and 1.8 cm in diameter fully expanded were used in 27 swine. (The stents were made in our research laboratory with the support of the Research and Development Department of Cook, Inc., Bloomington, Ind.) Simple 4-cm-long stents made of 0.051-cm (0.020-

[1] From the Departments of Diagnostic Radiology (L-340) (J.R., B.T.U., J.S.P., R.W.B.) and Pathology (R.D.L., A.L.H.), School of Medicine, Oregon Health Sciences University, 3181 S.W. Sam Jackson Park Road, Portland, OR 97201. From the 1986 RSNA annual meeting. Received September 11, 1986; accepted October 23. Supported by the Charles T. Dotter, M.D., Memorial Fund for Vascular Research and the Cook Memorial Fund through the Medical Research Foundation of Oregon. Address reprint requests to J.R.

inch) wire were applied in five swine. The "eyes" at the bends of the stent legs were connected by a fine monofilament line to control stent expansion to the desired diameter (Fig. 2b). Combination stents consisting of a 3–5-cm-long body made of 0.046-cm (0.018-inch) wire and a 1.5-cm-long skirt made of 0.036-cm (0.014-inch) wire were used in ten animals. The skirt was attached to the caudal end of the stent by a monofilament line (Fig. 2c). Stents with skirts on both sides of a 2.5- or 3-cm-long body, which was made of 0.041-cm (0.016-inch) wire, were applied in 12 swine (Fig. 2d). The stent was compressed, loaded within a 12-F Teflon cartridge, placed inside the adapter of the sheath, and advanced through it by a nontapered 10-F catheter containing a metal cannula (a pusher). In the last 24 animals, in which balloon stent distention was done, a 0.097-cm (0.038-inch) guide wire with a 0.046-cm (0.018-inch) tip was positioned inside the stent and the pusher; it was used for reintroduction of the balloon catheter. When the stent was pushed to the end of the sheath lying in the portal vein, its midportion was positioned in the previously marked liver puncture tract. The pusher was then held while the sheath was slowly withdrawn. This freed the stent, which expanded inside the liver puncture tract with its lower part lodged in the portal vein and its upper part in a hepatic vein or inferior vena cava. The stent was then distended with a 10-mm angioplasty balloon, establishing EIPCA. Portal venography followed via the transhepatic catheter to document its patency.

Follow-up portal venography was done by a transhepatic approach in swine with patent EIPCA at 1-week intervals up to 6 weeks. When the follow-up study showed EIPCA occlusion or after the 6-week portogram was obtained, an inferior venacavogram was obtained, the swine were killed, and detailed necroptic evaluation of the stent and liver was performed.

RESULTS

Good tapering and tight fitting of the inner coaxial catheter allowed introduction of the 10.5-F puncture system and then the 12-F Teflon sheath into the internal jugular vein, which is a delicate vessel in young swine. The liver puncture and portal entrance were relatively easily accomplished, particularly with puncture directly from the vena cava. The puncture with a 0.097-cm (0.038-inch) needle was atraumatic, and we encountered no intraabdominal or retroperitoneal bleeding at the animal's autopsy. The liver tract between both systems was 10–15 mm long and distended well with a high-pressure inflated balloon.

Correct placement of the original 3-cm-long stents was rather difficult. During final extrusion from the sheath, the stent "jumped" slightly distally, did not lodge centrally in the liver puncture tract, and did not distend evenly. A second stent introduced partially inside the first one (one swine) or above it (one swine) did not help. Immediate follow-up portograms did not show stent patency in any of the three swine; portacaval anastomosis was not established (Fig. 3).

Little success was also achieved in the first three swine with modified simple stents in which balloon stent distention was not done. These 4-cm-long stents were easier to place in the puncture tract; however, their distention was not sufficient. Initial portograms showed moderate EIPCA patency, but anastomoses were closed

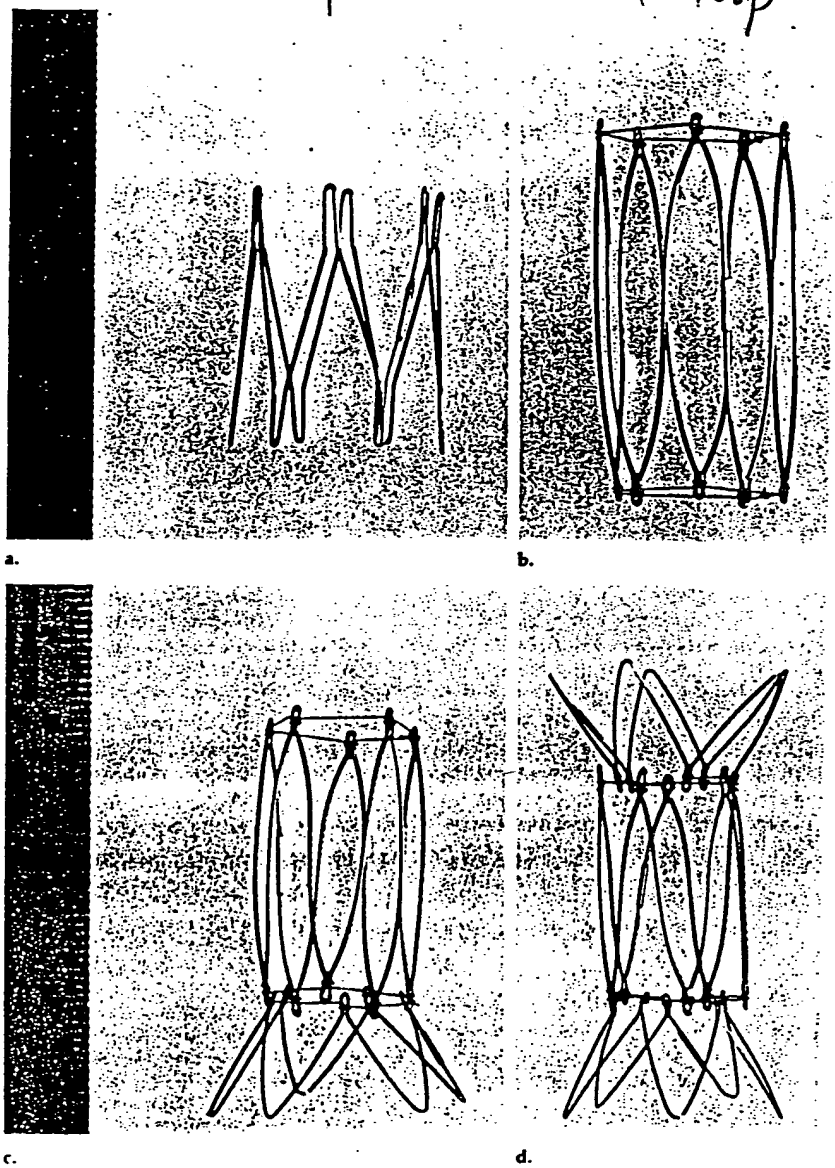


Figure 2. Types of stents used for creation of EIPCA. (a) Original Gianturco stent. (b) Modified simple 4-cm-long stent. (c) Combination stent with a 3-cm-long body and a skirt attached to its caudal end. (d) Combination stent with a 2.5-cm-long body and skirts attached to both ends.

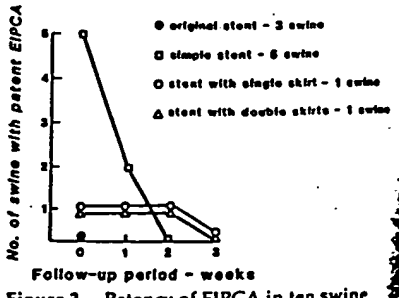
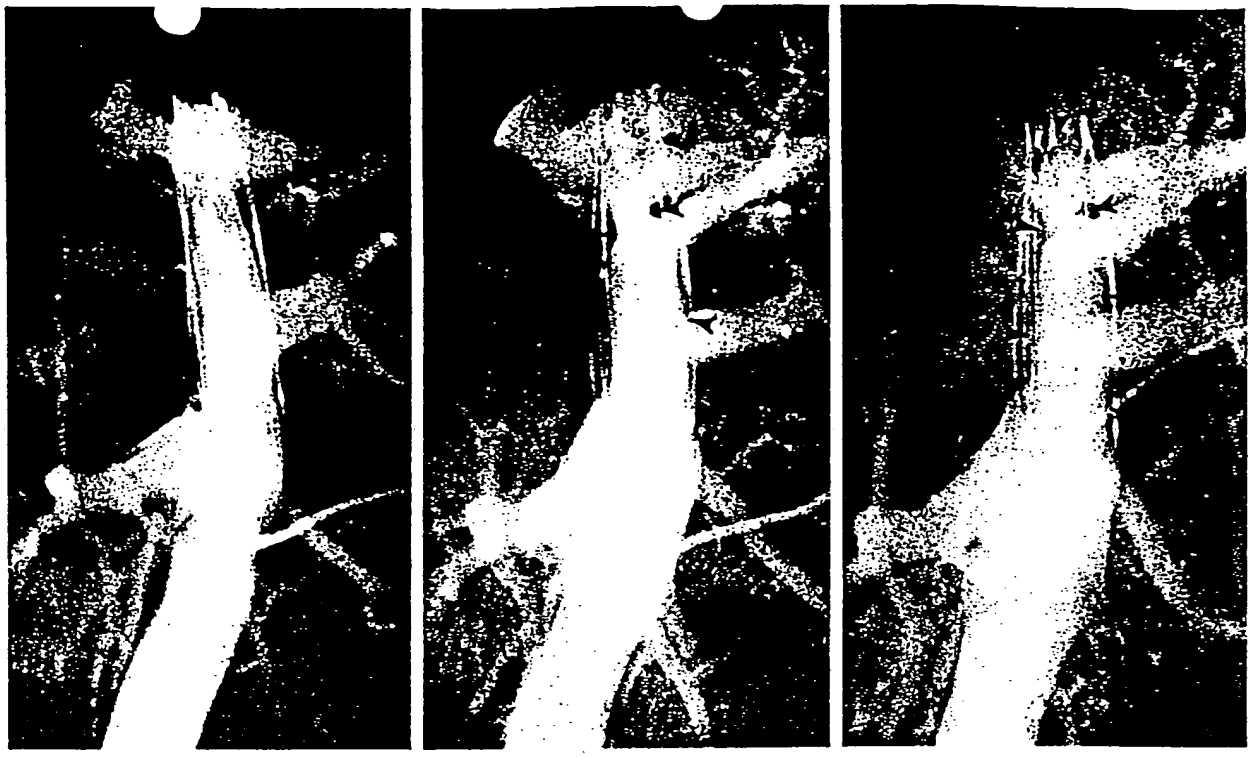


Figure 3. Patency of EIPCA in ten swine with liver puncture made from a hepatic vein.



a. b. c.

Figure 4. EIPCA created by liver puncture from a hepatic vein and placement of a single-skirt stent with a 5-cm-long body. EIPCA was found to be occluded at 3-week follow-up study. (a) Portogram obtained immediately after stent placement shows good patency of EIPCA. Cranial end of the stent rests against the upper wall of the hepatic vein, and flow is through the lateral wires of the stent. (b) One-week follow-up portogram shows good patency of EIPCA and some tissue ingrowth inside the stent (arrowheads), which is slightly expanded in diameter. (c) Two-week follow-up portogram shows increased tissue ingrowth inside the stent (arrowheads), particularly at its upper end, with minimal patency of EIPCA.

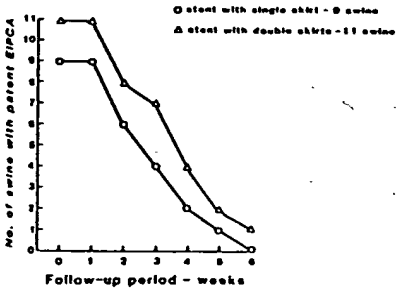
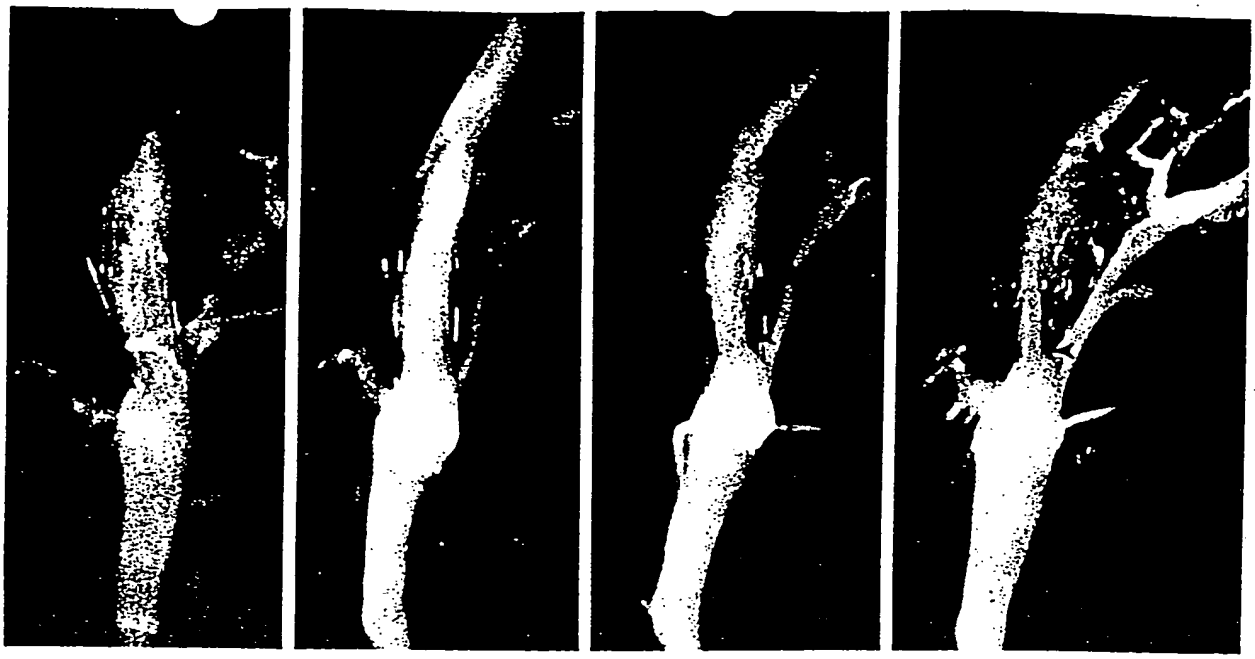


Figure 5. Patency of EIPCA in 20 swine with liver puncture made directly from the inferior vena cava.

on 1-week follow-up studies. Occlusion resulted from clot formation inside the stent. With balloon-stent distention, simple stents placed in two animals remained patent on the 1-week study with slightly decreased flow but were closed on the 2-week portogram. Oblique positioning of the stent so its caudal end was against the portal wall or its cranial end against the hepatic vein wall constituted a problem. Use of a stent with a single skirt (one swine) and a stent with double skirts (one swine) helped. The caudal skirt allowed central stent positioning in the portal vein. The cranial end, however, remained in position against the hepatic vein wall. The EIPCAs showed gradually decreasing patency on 1- and 2-week follow-up studies and were closed by the 3d week (Figs. 3, 4). At autopsy, abundant neointimal and connective-tissue proliferation was found inside the stents, particularly at their cranial ends positioned against the hepatic vein wall; clots were also present inside the stent.

Change of technique with liver puncture directly from the inferior vena cava improved EIPCA patency in the last 20 swine (Fig. 5). A single-skirt stent was placed in nine swine and a double-skirt stent in 11 swine. Initial follow-up portograms demonstrated excellent stent patency in all 20 animals; in eight of them, EIPCA diverted almost the entire portal flow into the caval circulation (Fig. 6). On the 1-week follow-up portograms, the EIPCA remained well patent; usually only minor narrowing was noted at the site where the stent traversed the liver parenchyma. This narrowing was mostly concentric but occasionally eccentric in nature. Later follow-up studies showed continued progression of this narrowing with concomitant flow decrease through the stent (Fig. 6). EIPCA patency and its closure were closely related to proper positioning of the stent, particularly to placement of its body inside the liver puncture tract. With optimal central placement, two single-skirt stents and four double-skirt stents remained patent, even with progressively decreasing blood flow, for 4 weeks, and one double-skirt stent remained patent for 6 weeks (Fig. 6). With suboptimal (too low or too high) stent placement, the shunt was patent for only 2–3 weeks (Fig. 5).

Filling of the intrahepatic portal branches seen on follow-up portograms progressively increased with decreasing patency of EIPCA (Fig. 6). With shunt closure, these branches were well-filled, and the left main portal branch was often slightly deformed and narrowed at the level of the placed stent. Inferior venacavograms at the end of the follow-up pe-



e.

Figure 6. EIPCA created by liver puncture directly from the inferior vena cava and placement of a double-skirt stent with a 2.5-cm-long body. EIPCA was found patent at the 6-week follow-up study. (a) Portogram obtained immediately after stent placement shows excellent patency of EIPCA. (b) Two-week follow-up portogram shows excellent patency of EIPCA and some tissue ingrowth inside the stent (arrowheads). (c) Four-week follow-up portogram shows increase of tissue ingrowth inside the stent (arrowheads) but continued, good EIPCA patency. (d) Six-week follow-up portogram shows further increase of tissue ingrowth inside the stent (arrowheads) and decreased EIPCA patency. (e) EIPCA specimen after 6-week follow-up study. The anterior portion of the stent was removed to document ingrowth of liver parenchyma and connective tissue inside its lumen (arrowheads). P = portal vein, C = inferior vena cava.

riod demonstrated some wall deformity and minor filling defects at the proximal end of the stents. These changes were more prominent in stents with upper ends protruding too far inside the caval lumen, but this did not constitute an obstruction to the caval flow.

Autopsy studies in swine with 4-6-week EIPCA patency showed fibrous tissue proliferation around the stent wires where they were in contact with the vessel wall. Most of the stents were incorporated in the vessel wall and covered with neointimal tissue except at the origin of side branches, which remained patent. EIPCA narrowing seen on follow-up portograms was caused partially by ingrowth of liver tissue into the stent between its wires, but mainly by abundant proliferation of the neointima and connective tissue (Fig. 6e). In the occluded shunts, clots were also present. Microscopic studies disclosed proliferation of granulation tissue, collagen, and scattered inflammatory cells at the site of the liver tract. The stents were covered with neointima consisting of fibrous connective tissue and lined by endothelium at the luminal surface.

DISCUSSION

The transjugular introduction of intravascular stents for creation of EIPCA was first described by Rösch et al. in 1969 (5). Initially using short 12- or 14-F Teflon tubings and later, covered spring coil tubings 5–6 mm in diameter, they created EIPCA in canines, which stayed patent for short periods, maximally for 12 days (6). Gutierrez and Burgener achieved EIPCA without a stent by simple balloon dilation of the liver puncture tract between a hepatic vein and the portal vein (7, 8). They were successful in canines with chronic portal hypertension; however, they experienced early EIPCA closures, necessitating repeated reopenings of the created anastomosis (9). Colapinto et al. have already used the balloon dilation technique for clinical creation of EIPCA (10). They achieved EIPCA in 15 patients with advanced cirrhosis and massive bleeding from esophageal varices after transjugular variceal obliteration (11). The anastomosis stayed patent for several weeks and resulted in a

and
ent at
e-
ws
ids).
stent
gram
eased
por-
on-
cava.

ent for
for 12 days
er achieved
simple bal-
puncture
in and the
ere success-
ic portal hy-
y experi-
es,
openings of
9). Cola-
ised the bal-
or clinical
hey
tients with
assive
il varices af-
obliteration
yed patent
sulted in a

decrease in portal pressure of 5–15 mm Hg. The majority of patients, however, soon experienced rebleeding or died. A simple balloon dilation of the cirrhotic liver probably did not create sufficiently large anastomosis to maintain its prolonged function with significant blood flow. Expandable wire stents promise to fulfill this need and to allow prolonged significant portacaval shunting. Introduced through relatively small catheters in a compressed form, they expand inside the liver puncture tract, and their expanding force is capable of continued dilation of the created anastomosis.

Palmaz et al. successfully created a long-term functioning EIPCA with their design of an expandable mesh stent, originally made of stainless steel woven wire, now obtained from thin-walled stainless steel tubing by electromagnetic etching (12). Using canines with induced portal hypertension, they found that EIPCAs remained open and functioning well for up to 10 months and effectively decreased portal hypertension (13). Pathologic examination showed complete endothelialization of the inner surface of the stents and their inclusion into the vascular wall (12).

Our experimental work documents that the Gianturco stents made from stainless steel wire in a zigzag pattern are also well suited for EIPCA. These stents are versatile: They can be made in various sizes, diameters, lengths, and degrees of expansile force and can be connected together depending on the anatomic needs. They are easy to construct: All our stent modifications were handmade in our research laboratory. Of the tested modifications, the triple stent with a 2.5- or 3-cm-long body and wire skirts on both ends was most suitable for EIPCA. The stent with the 2.5-cm-long body was somewhat difficult to place centrally in the liver puncture tract because of respiratory liver motion. However, short respiratory arrest and contrast material injection through the transhepatic portal catheter during stent positioning helped achieve optimal stent placement. The caudal stent skirt was essential for central positioning of the stent in the portal vein lumen; stents without it rapidly occluded. The cranial skirt kept the upper stent end well distended and positioned in the inferior vena cava. However, it was not essential, as several single-skirt stents had almost the same patency as the double-skirt stents.

Selection of puncture site of the liver and portal vein was of primary importance for stent placement and EIPCA patency. Best results were achieved with puncture directly from the inferior vena cava, avoiding hepatic vein entrance. The liver puncture tract with such a puncture was only 10–15 mm long, and its orientation favored good EIPCA flow. The well-placed stent was almost a continuation of the portal vein.

Young domestic swine were good experimental animals for development of stent application technique and evaluation of short-term EIPCA patency. However, their rapid growth and regenerative ability prevented long-term observation. With a successfully established EIPCA and shunting of the majority of portal blood into the caval circulation, the swine had minimal weight gain for about 1–2 weeks. With decreasing EIPCA patency, their weight increased an average of 2 kg in a week.

The EIPCA patency was closely related to the distention and position of the stent. Balloon distention of the stent after its placement was essential for its patency; the intrinsic expandable tension of the stent did not have enough force to open it inside the liver tract to a sufficiently large lumen. Similarly important was a central position of the stent in the liver puncture tract. With slight caudal or cranial misplacement of the stent, the EIPCA was not functioning well and closed in 2–3 weeks. Early stent closures were mainly related to thrombus formation inside the stent resulting from poor blood flow. Later closures in well-placed stents were caused partially by ingrowth of liver parenchyma between the stent wires, but mainly by abundant proliferation of connective tissue and neointima inside the stent. Clot formation contributed to the final EIPCA closure after the tissue ingrowth decreased blood flow through the stent. Palmaz et al. did not observe similar liver ingrowth and neointimal and connective-tissue hyperproliferation with use of their mesh stents in adult, nongrowing canines (12). The cause of this event in our study, whether related to the stent itself, rapid growth of animals without portal hypertension, or both of these factors, cannot be explained by the information collected. This will have to be answered by future experimental studies. ■

References

1. Wright KC, Wallace S, Charnsangavej C, Carrasco CH, Gianturco C. Percutaneous endovascular stents: an experimental evaluation. Radiology 1985; 156:69–72.
2. Carrasco CH, Wallace S, Charnsangavej C, et al. Expandable biliary endoprosthesis: an experimental study. AJR 1985; 145:1279–1281.
3. Wallace MJ, Charnsangavej C, Ogawa K, et al. Tracheobronchial tree: expandable metallic stents used in experimental and clinical applications. Radiology 1986; 158:309–312.
4. Uchida B, Putnam J, Buschman R, Rösch J. "Atraumatic" transjugular needle for portal vein puncture in swine (forthcoming).
5. Rösch J, Hanafee WN, Snow H. Transjugular portal venography and radiologic portacaval shunt: an experimental study. Radiology 1969; 92:1112–1114.
6. Rösch J, Hanafee W, Snow H, Barenfus M, Gray R. Transjugular intrahepatic portacaval shunt. Am J Surg 1971; 121: 588–592.
7. Gutierrez OH, Burgener FA. Production of nonsurgical portosystemic venous shunts in dogs by transjugular approach. Radiology 1979; 130:507–509.
8. Burgener FA, Gutierrez OH. Nonsurgical production of intrahepatic portosystemic venous shunts in portal hypertension with the double lumen balloon catheter. ROFO 1979; 130:686–688.
9. Burgener FA, Gutierrez OH. Produktion einer intrahepatischen portokavalen Fistel im Hund mit Leberzirrhose und Pfortaderhochdruck. ROFO 1984; 141:327–332.
10. Colapinto RF, Stronell RD, Gildiner M, et al. Formation of intrahepatic portosystemic shunts using a balloon dilatation catheter: preliminary clinical experience. AJR 1983; 140:709–714.
11. Abecassis M, Gordon JD, Colapinto RF, et al. The transjugular intrahepatic portosystemic shunt (TIPS): an alternative for the management of life-threatening variceal hemorrhage. Hepatology 1985; 5:1032.
12. Palmaz JC, Sibbitt RR, Reuter SR, Garcia F, Tio FO. Expandable intrahepatic portacaval shunt stents: early experience in the dog. AJR 1985; 145:821–825.
13. Palmaz JC, Garcia F, Sibbitt RR, et al. Expandable intrahepatic portacaval shunt stents in dogs with chronic portal hypertension. AJR 1986; 147:1251–1254.

COURSE OUTLINE

SOCIETY OF CARDIOVASCULAR AND INTERVENTIONAL RADIOLO
OFFERS ITS TWELFTH ANNUAL COURSE
DIAGNOSTIC ANGIOGRAPHY AND INTERVENTIONAL RADIOLOGY

Hotel Inter-Continental
San Diego, California
March 23-26, 1987

ONDAY – MARCH 23, 1987

00-7:45 AM CONTINENTAL BREAKFAST
45-8:00 AM WELCOME & ANNOUNCEMENTS
Thomas A. Sos, M.D.,
President, SCVIR
DERATOR: *Herbert L. Abrams, M.D.)*
00-8:20 AM "PHARMACO-ARTERIOGRAPHY IN THE EVALUATION OF IMPOTENCE"
Joseph J. Bookstein, M.D.
20-8:40 AM "RADIOLOGIC DIAGNOSIS AND STAGING OF HEPATIC NEOPLASMS"
Patrick C. Pratty, M.D.
40-9:00 AM "APPROACHES TO THE DIAGNOSIS OF PULMONARY EMBOLISM"
Arthur C. Waltman, M.D.
00-9:20 AM "A CRITICAL LOOK AND UPDATE ON VENA CAVAL FILTERS"
Christos A. Athanasoulis, M.D.
20-9:40 AM "DIGITAL SUBTRACTION ARTERIOGRAPHY IN CONGENITAL HEART DISEASE"
Ina L. Tonkin, M.D.
40-10:00 AM "PHARMACO-CAVERNOSOGRAPHY AND MANOMETRY IN THE EVALUATION OF IMPOTENCE"
Joseph J. Bookstein, M.D.
00-10:20 AM "ADVANCES AND CURRENT STATUS OF CONTRAST AGENTS"
Michael A. Bettmann, M.D.
20-10:40 AM "DIAGNOSIS AND EVALUATION OF AORTIC ANEURYSMS – THE ROLE OF MRI"
Murray Baron, M.D.
40-11:00 AM COFFEE BREAK
ERATOR: *Joseph J. Bookstein, M.D.)*
00-11:40 AM "THE VALUE OF NON-INVASIVE IMAGING TECHNIQUES FOR THE DIAGNOSIS OF MEDIASTINAL MASSES"
Manuel Viamonte, Jr., M.D.
40-12:00 PM "EVALUATION OF CARDIOVASCULAR FUNCTION BY MRI: CINE MAGNETIC RESONANCE IMAGING"
Charles B. Higgins, M.D.
00-12:20 PM "MRI OF CONGENITAL HEART DISEASE"
Murray J. Moser, M.D.
20-12:40 PM "MRI OF LIVER DISEASES"
Antonios S. Gomes, M.D.
40-1:00 PM "ADRENAL MRI: THE END OF ADRENAL ANGIOGRAPHY"
John L. Doppman, M.D.
00-1:20 PM "MAGNETIC RESONANCE IMAGING ANGIOGRAPHY"
Edward Buonocore, M.D.
20-4:30 PM WORKSHOPS

ESDAY – MARCH 24, 1987

00 AM CONTINENTAL BREAKFAST
ERATOR: *Wilfrido R. Castaneda, M.D.)*
00-8:15 AM "NON-INVASIVE DOPPLER ANGIOGRAPHY AS A PRELUDE TO ARTERIOGRAPHY & INTERVENTION"
James R. LaPage, M.D.
15-8:30 AM "DIGITAL ANGIOGRAPHY IN THE EVALUATION OF PERIPHERAL VASCULAR DISEASE"
Helen C. Redman, M.D.
30-8:45 AM "PERCUTANEOUS ANGIOSCOPY"
Amil Nasrallah, M.D.
45-9:05 AM "ILIOFEMORAL PERCUTANEOUS TRANSLUMINAL ANGIOPLASTY"
Robert J. Eason, M.D.
05-9:25 AM "TIBIAL PERCUTANEOUS TRANSLUMINAL ANGIOPLASTY"
Donald W. Schwarten, M.D.
25-9:40 AM "RECENT DEVELOPMENTS IN CORONARY ANGIOPLASTY"
40-10:00 AM "RENAL PERCUTANEOUS TRANSLUMINAL ANGIOPLASTY: METHODS"
Charles J. Tegtmeyer, M.D.
00-10:20 AM "RENAL PERCUTANEOUS TRANSLUMINAL ANGIOPLASTY: RESULTS"
Thomas A. Sos, M.D.
20-10:40 AM "PREDICTING RECURRENCES FOLLOWING PERCUTANEOUS TRANSLUMINAL ANGIOPLASTY"
Robert L. White, Jr., M.D.
40-11:20 AM COFFEE BREAK
MODERATOR: *Mark H. Wholey, M.D.)*
20-11:40 AM "RECENT DEVELOPMENTS IN FIBRINOLYTIC THERAPY"
Barry T. Katzen, M.D.
40-11:55 AM "PERCUTANEOUS ATHERECTOMY"
Donald E. Schwarten, M.D.
55-12:05 PM "ATHEROLYTIC WIRE FOR TOTALLY OBSTRUCTED VESSELS"
Mark H. Wholey, M.D.
05-12:25 PM "PERCUTANEOUS ANGIOPLASTY WITH HOT TIP LASER"
Alan J. Greenfield, M.D.
25-12:45 PM "EXCIMER LASER ANGIOPLASTY"
Donald E. Schwarten, M.D.
45-1:05 PM "THE CURRENT STATUS OF VASCULAR PROSTHESES"
Julio C. Palmaz, M.D.
05-1:20 PM "GIANTURCO EXPANDABLE STENTS IN CLINICAL & EXPERIMENTAL USE"
Josef Rösch, M.D.
00-6:30 PM WORKSHOPS

WEDNESDAY – MARCH 25, 1987

00-7:15-8:00 AM CONTINENTAL BREAKFAST
MODERATOR: *Robert L. White, Jr., M.D.)*
00-8:20 AM "LEGAL PROBLEMS OF INTERVENTIONALISTS"
Stewart Bauer, M.D.
20-8:40 AM "ECONOMIC & PRACTICAL IMPACT OF INTERVENTIONAL RADIOLOGY ON THE PRACTICE OF MEDICINE"
William J. Casarella, M.D.
40-9:00 AM "POTENTIAL CONFLICTS IN INTERVENTIONAL RADIOLOGY"
P. Ruben Koehler, M.D.
00-9:25 AM "PRACTICAL ASPECTS OF DEALING WITH THE CHANGING AMERICAN HEALTH CARE SYSTEM"
Robert Stein, Ph.D.

SPECIAL LECTURE HONORING DR. CHARLES T. DOTTER

35-9:45 AM "INTRODUCTION OF DOTTER LECTURER"
Thomas A. Sos, M.D.
45-10:25 AM "DOTTER LECTURE:" THE INTERVENTIONALIST'S IMPACT ON THE PRACTICE OF RADIOLOGY"
Stanley Baum, M.D.

Supported by Cook, Inc.

25-11:00 AM COFFEE BREAK
MODERATOR: *Edward M. Dorp, M.D.)*
00-11:20 AM "APPROACH FOR PERCUTANEOUS NEPHROSTOMY"
Wilfrido R. Castaneda, M.D.
20-11:40 AM "ANTEGRADE URETERAL STENTING"
Harold A. Harp, M.D.
40-12:00 PM "URETERAL STRICTURE DILATATION"
Andrew B. Crummy, M.D.
00-12:20 PM "PER
M.
20-12:40 PM "PER
VASCI
C.
40-1:00 PM "MAN
ABSC
Er

4:00-5:00 PM
Organizational m

00-6:30 PM WORK

THURSDAY

15-8:00 AM CONT
MODERATOR: *Thomas A*
00-8:20 AM "PRED
RESUL
Ivo
20-8:40 AM "BILIA
Ala
40-9:00 AM "ELECT
Mar
00-9:20 AM "PERC
EXTRA
Mah
20-9:40 AM "BILIA
Ern
40-10:00 AM "EMBO
CONSI
Jam
00-10:15 AM "COIL F
OCCLU
Cam
15-10:35 AM "EMBOL
You
35-11:15 AM COFFEE
MODERATOR: *Kyung J. C*
15-11:35 AM "ANGIO
ARTERI
ARTERI
Fred
35-11:55 AM "DIAGN
FOR HA
Kiam
55-12:15 PM "UPDAT
Sally
15-12:35 PM "RENAL
Vivia
35-12:55 PM "EMBOL
NEUROI
Sidn
55-1:15 PM "TRANS
NEOPLA
Chu
15-1:35 PM "SPLENI
Dou
35 PM ADJOUR

WORKSHOP

Classes of Workshops each day
for FIVE hours per day) 5:00-

BILIARY/G.I.
DEBTS, THE BLUES, TURF
EMBOLOTHERAPY
G.I. INTERVENTION
LASER APPLICATIONS
NONINVASIVE CARDIOV

GIANTURCO EXPANDABLE STENTS IN EXPERIMENTAL AND CLINICAL USE

J. Rösch, J. Putnam, B. Uchida

Gianturco expandable stents (GES) were designed for percutaneous stenting of medium-sized and large vascular and ductal structures. They were tested in animals for application in venous, arterial, portal and biliary systems and the tracheobronchial tree and successfully used on an experimental basis in a few patients (1-7). GES are still in a developmental stage, but there is a reasonable hope that they will be available for clinical use in the not-too-distant future.

GES are constructed of stainless steel wire 0.014-0.020 inch in diameter, which is bent in a zigzag pattern with ends joined to form a cylinder. They are compressed in a cartridge and introduced percutaneously through a catheter. A small diameter stent (5 to 10mm) is introduced through a 9F catheter and large stent (15 to 40mm) through a 12F catheter. After being released inside a vessel, GES expand, and their expanding force is capable of dilating a narrowed vascular or ductal lumen. With high degree stenoses, when the expanding force of the stent is not sufficient, a balloon catheter is used to expand the stent to a desirable lumen. Continued slight expansion of the stents was observed during a period of time in the tracheobronchial tree and venous system (4,7). A monofilament line attached to the ends of the stent legs was found to be useful to limit the stent expansion to a desirable diameter (6,7).

GES are 2 to 4 cm long, and the stent length is selected depending on the lesion

to be stented. In longer lesions, two or more 2 cm long stents are connected by a wire strut or monofilament line to form a stent combination (5, 7). A wire skirt attached to one or both ends of the stent was found to be useful to keep a central position of the stent end in the vascular lumen (6, 7). The attached skirt also helps to prevent stent dislodgement. Small hooks can be added to the stent or skirt to insure a fixed position of the stent in a large vessel and prevent stent migration (5, 7).

GES are highly promising for dilating and stenting large veins and arteries. In experimental stenosis of the inferior vena cava of canines, GES placement resulted in a long term (4 months) dilation of the stenosis and improved hemodynamics (5). GES also have a good potential in the treatment of aortic dissection, as was demonstrated in vitro on experimentally induced dissections of aortic specimens (3). Intravascular GES exhibit low thrombogenicity; placed in the canine vena cava and aorta, they stayed widely patent for 5 to 6 months, until the animals were sacrificed (1). Cellular proliferation occurred early around the wires in contact with the intima, and in 4 weeks, the venous stents were almost completely endothelialized and incorporated in the venous wall. In arteries this process took about 3 months. Blood vessels whose origins were bridged by the stent remained open. Only minimal cellular growth was observed on wire segments bridging the renal veins in canines after the stents were in place for 6 months (1).

GES offer a realistic chance for a transjugularly performed intrahepatic portacaval shunt for treatment of massive variceal bleeding in patients with portal hypertension (8). Creation of such an experimental shunt using GES was successfully achieved in young domestic swine without portal hypertension (6). Well-positioned

stents shunted most of the portal blood into the IVC circulation and remained patent for 4 to 6 weeks. Ingrowth of the liver parenchyma and hyperproliferation of neointima in rapidly growing animals gradually decreased shunt patency. The hyporegenerative livers of cirrhotic patients are not expected to react in this way.

Promising results were also obtained with experimental use of GES in the biliary system and tracheobronchial tree in canines. Small diameter stents (5 to 10mm) were placed as endoprostheses in the common bile duct and large stents (20 to 40mm in diameter) in the trachea and bronchus. The stents remained well distended over weeks to months and caused only mild inflammatory reaction (2,4).

Clinical experience with GES is very limited but highly promising. GES were used in a few patients for palliation of lesions or syndromes which were difficult or impossible to manage by other means. Tracheal and bronchial stents were placed with good results and no side effects for palliation of severe postsurgical stenoses or after surgical failure of tracheal reconstruction (4). Excellent results were also achieved with the use of GES for dilation of stenoses of inferior and superior vena cava, particularly for relief of the SVC syndrome (4, 5, 7). A large dilating balloon catheter had to be used to fully expand the stent in a firm SVC stenosis caused by tumor invasion and postradiation fibrosis. Stent placement resulted in immediate relief of symptoms. In our two patients with SVC syndrome recurring after maximum tolerance radiation where no other treatment could be used, GES placement resulted in long term palliation (9 months, until submission of this abstract) of severe SVC syndrome symptoms (7).

REFERENCES

1. Wright KC, Wallace S, Charnsangavej, et al: Percutaneous Endovascular Stents: An Experimental Evaluation. Radiology 1985; 156:69-72.

2. Carrasco CH, Wallace S, Charnsangavej C, et al: Expandable Biliary Endoprosthesis: An Experimental Study. AJR 1985; 145:1279-1281.

3. Charnsangavej C, Wallace S, Wright KC, et al: Endovascular Stent for Use in Aortic Dissection: An in Vitro Experiment. Radiology 1985; 157:323-324.

4. Wallace MJ, Charnsangavej C, Ogawa K, et al: Tracheobronchial Tree: Expandable Metallic Stents Used in Experimental and Clinical Applications. Work in Progress. Radiology 1986; 158:309-312.

5. Charnsangavej, C, Carrasco, Wallace S, et al: Stenosis of the Vena Cava: Preliminary Assessment of Treatment with Expandable Metallic Stents. Radiology 1986; 161:295-298.

6. Rösch J, Uchida B, Putnam J, et al: Expandable Gianturco Stents in Experimental Intrahepatic Portacaval Anastomosis. Radiology, in press.

7. Rösch J, Bedell JE, Putnam J, et al: Gianturco Expandable Wire Stents in the Treatment of Superior Vena Cava Syndrome Recurring After Maximum Tolerance Radiation. Report of Two Cases. Submitted, Cancer.

8. Rösch J: Nonsurgical Intrahepatic Portacaval Shunt: A Utopian Dream or an Approaching Reality? Hepatology 6:1056-1058, 1986.